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ESTIMATING THE ENVIRONMENT AND THE RESPONSE OF SPRINKLER LINKS IN COMPARTMENT FIRES WITH DRAFT CURTAINS AND FUSIBLE- LINK-ACTUATED CEILING VENTS - PART II: USER GUIDE FOR THE COMPUTER CODE LAVENT

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Estimating the Environment and the Response of Sprinkler Links in Compartment Fires with Draft Curtains and Fusible-Link-Actuated Ceiling Vents - Part II: User Guide for the Computer Code LAVENT

William D. Davis and Leonard Y. Cooper

ABSTRACT

This is a User Guide for the computer code LAVENT (Link-Actuated VENTs) and an associated graphics code GRAPH. LAVENT has been developed to simulate the environment and the response of sprinkler links in compartment fires with draft curtains and fusible-link-actuated ceiling vents.

A fire scenario simulated by LAVENT is defined by the following input parameters: area and height of the curtained space; floor-to-bottom-of-curtain separation distance; length of the curtain (a portion of the perimeter of the curtained space can include floor-to-ceiling walls); thickness and properties of the ceiling material (density, thermal conductivity, and heat capacity); constants which define a specified time-dependent energy-release-rate of the fire; fire elevation; area or characteristic energy-release-rate per unit area of the fire; total area of ceiling vents whose openings are actuated by a single fusible link (multiple vent-area/link system combinations are allowed in any particular simulation); and identifying numbers of fusible links used to actuate single sprinkler heads or groups of sprinkler heads (multiple sprinkler links are allowed in any particular simulation).

The characteristics of the simulated fusible links are defined by the following input parameters: radial distance of the link from the fire/ceiling impingement point; ceiling/link-separation distance; link fuse temperature; and the response-time-index (RTI) of the link.

For any particular run of LAVENT, the code outputs 1) a summary of the input information and 2) simulation results of the calculation, in tabular form, at uniform simulation-time intervals requested by the user. The output results include: temperature of the upper smoke layer; height of the smoke-layer interface; total mass in the layer; fire energy-release-rate; radial distributions of the lower ceiling surface temperature; radial distribution of heat-transfer rates to the lower and upper ceiling surfaces; and for each link, the temperature, and the local velocity and temperature of the ceiling jet.

The use of LAVENT is presented by a series of exercises in which the reader reviews and modifies a default input data file which describes vent and sprinkler actuation during fire growth in an array of wood pallets located in a warehouse-type occupancy. Results of the default simulation are discussed.

LAVENT is written in FORTRAN 77. The executable code operates on IBM PC-compatible computers and requires a minimum of 300 kilobytes of memory.

Keywords: building fires; compartment fires; computer models; fire models; mathematical models; vents; sprinkler response; zone models.

1. Introduction - The Phenomena Simulated by LAVENT

This is a User Guide for the computer code LAVENT (Link-Actuated VENTs). LAVENT has been developed to simulate the environment and the response of sprinkler links in compartment fires with draft curtains and fusible-link-actuated ceiling vents.

Figure 1 depicts the generic fire scenario simulated by LAVENT. This involves a fire in a building space with ceiling-mounted draft curtains and near-ceiling fusible-link-actuated ceiling vents and sprinklers. The curtained area can be considered as one of several such spaces in a single large building compartment. By specifying the curtains to be deep enough they can be thought of as simulating the walls of a single uncurtained compartment, well-ventilated near the floor.

The fire generates a mixture of gaseous and solid-soot combustion products. Because of high temperature, buoyancy forces drive the products upward toward the ceiling forming a plume of upward moving hot gases and particulates. Cool gases are laterally entrained and mixed with the plume flow, reducing its temperature as it continues its ascent to the ceiling.

When the hot plume flow impinges on the ceiling, it spreads under it, forming a relatively thin, high-temperature ceiling-jet. There is reciprocal convective cooling and heating of the ceiling-jet and the cooler lower ceiling surface, respectively. The lower ceiling surface is also heated due to radiative transfer from the combustion zone and cooled due to re-radiation to the floor of the compartment. The compartment floor is assumed to be at ambient temperature. The upper ceiling surface is cooled as a result of convection and radiation to a far-field, ambient-temperature environment.

When the ceiling jet reaches a bounding vertical draft curtain or wall surface, its flow is redistributed across the entire curtained area and begins to form a relatively quiescent, now-somewhat-reduced-temperature smoke layer which submerges the continuing ceiling-jet flow activity. The upper smoke layer grows in thickness. Away from bounding surfaces, the time dependent layer temperature is assumed to be relatively uniform throughout its thickness. (Note that the thickness and temperature of the smoke layer affects the upper-plume characteristics, the ceiling-jet characteristics, and heat-transfer exchanges to the ceiling.)

If the height of the bottom of the smoke layer drops to the bottom of the draft curtain and continues downward, the smoke will begin to flow below the curtain into the adjacent curtained spaces. The growth of the upper layer will be retarded.

Fusible links, designed to actuate the opening of ceiling vents and the onset of water flow through sprinkler heads, are deployed at specified distances below the ceiling and at specified radial distances from the plume/ceiling impingement point. These links are submerged within the relatively high-temperature, high-velocity ceiling-jet flow. Since the velocity and temperature of the ceiling jet varies with location and time, so would the heat transfer to and time-of-fusing of any particular link design.

The fusing of a ceiling-vent link leads to the opening of all vents "ganged" to that link. Once a ceiling vent is open, smoke will flow out of the curtained space. Again, as when smoke flows below the curtains, growth of the upper layer thickness will be retarded.

The fusing of a sprinkler link initiates flow of water through the sprinkler head.

All of the above phenomena, up to the time that water flow through a sprinkler head would be initiated, are simulated by LAVENT. Results can not be used after water begins to flow through a sprinkler head.

A detailed programmer guide to the LAVENT computer code will be presented in [1]. The physical basis and the model equations for the code have been developed and presented in [2] with an overview in [3].

2. The Default Simulation

Use of LAVENT will be discussed and illustrated below by going through exercises in reviewing and/or modifying the LAVENT default-simulation input file. To appreciate the process better, a brief description of the default simulation will be presented at the outset.

Refer to Figure 2. The default scenario involves a 84.0 ft x 84.0 ft curtained compartment (7056.0 ft^2 in area) with the ceiling located 30.0 ft above the floor. A draft curtain 15.0 ft in depth surrounds completely and defines the compartment which is one of several such compartments in a larger building space. The ceiling is constructed of a relatively thin sheet-steel lower surface which is well-insulated from above.

The curtained compartment has four, uniformly spaced, 48.0 ft^2 ceiling vents with a total area of 192 ft^2, or 2.7 percent of the compartment area. Opening of the ceiling vents is actuated by quick-response fusible links with RTIs of 50.0 $(ft \cdot s)^{1/2}$ and fuse temperatures of 165.0 F. The links are located at the centers of the vents and 0.3 ft below the ceiling surface.

Fusible-link-actuated sprinkler heads are deployed on a square grid with 12.0 ft spacing between heads. The links have RTIs of 400.0 $(ft \cdot s)^{1/2}$ and fuse temperatures of 165.0 F. The heads and links are mounted 1.0 ft below the ceiling surface.

The simulation fire involves four abutting 5.0 ft-high stacks of 5.0 ft x 5.0 ft wood pallets. The combined grouping of pallets makes up a combustible array 10.0 ft x 10.0 ft (100 ft^2 in area) on the floor and 5.0 ft in height. It is assumed that other combustibles in the curtained compartment are far enough away from this array that they will not be ignited in the time interval to be simulated.

The total energy-release-rate of the simulation fire, $\dot{Q}$, is assumed to grow from ignition, at time $t = 0$, in proportion to t^2. According to the guidance

in Table 4-2 of [4], in the growth phase of the fire $\dot{Q}$ is taken specifically as

$$\dot{Q} = 1000.[t/(130\ s)]^2\ BTU/s$$

The fire grows according to the above estimate until the combustibles are fully involved. Then it is assumed that $\dot{Q}$ levels off to a relatively constant value. Following again the guidance of [4] (see Table 1), it is estimated that at the fully developed stage of the fire the total energy-release-rate for the 5.0 ft high stack of wood pallets will be 330. (BTU/s)/ft^2, or 33000. BTU/s for the entire 100. ft^2 array. The above equation leads to the result that the fully developed stage of the fire will be initiated at t_{f-d} = 747. s.

A plot of the fire growth according to the above description is presented in Figure 3. In the actual calculation, the fire's instantaneous energy-release-rate is estimated by interpolating linearly between a series of N input data points at times t_n, n = 1 to N, on the fire-growth curve. These points are defined by user-specified values of $[t_n, \dot{Q}(t_n)]$. For times larger than t_N, the fire's energy-release-rate is assumed to stay constant at $\dot{Q}(t_N)$. The calculation fire-growth curve involves six input data points, i.e., N = 6. These points are plotted in Figure 3.

The position of the center of the fire is identified in Figure 2. In terms of this plan view, the fire is assumed to be located at the midpoint of a 12.0 ft line between two sprinkler links, at a distance of 21.2 ft from each of the two closest equidistant vents (total area of 96.0 ft^2), and at a distance of 44.3 ft from the remaining two equidistant vents (total area of 96.0 ft^2). Of the sprinklers and associated links, two are closest and equidistant to the fire-plume axis at radial distances of 6.0 ft. Note from Figure 2 that the second and third closest groups of sprinkler heads and links are at radial distances of 13.4 ft (four heads and links) and 18.0 ft (two heads and links). In the default calculation, opening of each of the four vents occurs, and flow out of the vents is initiated at the simulated time of fusing of their associated links, Also simulated in the default calculation is the thermal response, including time-of-fusing, of the pair of sprinkler links closest to the fire.

As a final specification of the fire, it is assumed that the characteristic elevation of the fire remains at a fixed value, 2.5 ft above the floor, at the initial mid-elevation of the array of combustibles.

For the purpose of the default calculation, the simulation will be carried out to t = 400. s, with data output every 30. s.

Having described the default simulation, the procedure for getting started and using LAVENT is now presented.

3. Getting Started

The executable code, LAVENT.EXE, is found on the floppy disk. Before using it, backup copies should be made. If the user has a hard drive, a separate directory should be created and the executable code copied into that directory. The code operates on an IBM PC[1] or compatible containing a math coprocessor. It is written in Fortran 77 and requires a minimum of 300 kilobytes of memory.

To execute LAVENT, change to the proper directory or insert a floppy disk containing a copy of the executable code and enter LAVENT [ret]. Here [ret] refers to the ENTER or RETURN key. The first prompt will be:

ENTER 1 FOR ENGLISH UNITS, 2 FOR METRIC UNITS

The program has a unit conversion routine and will transform files that are in one set of units to the other set. The code executes in SI units and so conversion is only done on input and output in order to avoid rounding errors.

For the purposes of "getting started," choose Option 1, ENGLISH UNITS. Enter 1 [ret]. The following menu will be displayed on the screen:

1 READ AND RUN A DATA FILE
2 READ AND MODIFY A DATA FILE
3 MODIFY THE DEFAULT CASE TO CREATE A NEW FILE
4 RUN THE DEFAULT CASE

If Options 1 or 2 are chosen, the program will ask for the name of the data file that will be used. If the chosen file resides on the hard disk, this question should be answered by typing the path of the file name, for example C:\subdirectory\filename. If the file is on a floppy disk, type A:filename or B:filename depending on whether the A or B drive is being used. It is suggested that all data files use a common extender such as .DAT in order to facilitate identification of these files.

A first-time user should select Option 4 RUN THE DEFAULT CASE by entering 4 [ret]. This will insure that the code has been transferred intact. A copy of the default-case output is presented in Figure 4. As a point of information, the time required to carry out the default simulation on the Compaq 386/20e[1] and the IBM AT[1] is approximately 12 and 90 minutes, respectively.

Now restart the code and at this point choose Option 3 MODIFY THE DEFAULT CASE to review and modify the default input data. Enter 3 [ret].

---

[1]The use of trade names are for clarification only, and should not be construed as endorsement by the National Institute of Standards and Technology.

4. The Base Menu

When Option 3 MODIFY THE DEFAULT CASE is chosen, the following menu is displayed:

```
1       ROOM PROPERTIES
2       PHYSICAL PROPERTIES
3       OUTPUT PARAMETERS
4       FUSIBLE LINK PROPERTIES
5       FIRE PROPERTIES
6       SOLVER PARAMETERS
0       NO CHANGES
```

This will be referred to as the "base menu."

Entering the appropriate option number of the base menu and then [ret] will always transfer the user to the indicated item on the menu. Entering a zero will transfer the user to the file status portion of the input section to be discussed in Section 5.

The next five sections will discuss data entry under Options 1 through 5 of the base menu. Option 6 SOLVER PARAMETERS will typically not be required. For this reason data entry for Option 6 will be discussed in the Appendix.

Now choose Option 1 ROOM PROPERTIES of the base menu to review and/or modify the default room-property input data. Enter 1 [ret].

4.1 Room Properties

When Option 1 ROOM PROPERTIES of the base menu is chosen, the following room-properties menu is displayed:

```
1          30.00000      CEILING HEIGHT (FT)
2          84.00000      ROOM LENGTH (FT)
3          84.00000      ROOM WIDTH (FT)
4        2               NUMBER OF VENTS, ETC.
5        336.00000       CURTAIN LENGTH (FT)
6          15.00000      HEIGHT TO BOTTOM OF CURTAIN (FT)
0                        TO CHANGE NOTHING
```

All input values are expressed in either Scientific Internationale or English units and the units are prompted on the input menus.

Note that the default number of vents is 2 and not 4 since the symmetry of the default scenario, as indicated in Figure 2, leads to "ganged" operation of each of two pairs of the four vents involved.

To change an input value in the above room-properties menu, for example, to change the ceiling height from 30. ft to 20. ft, the user would enter 1 [ret] and 20. [ret]. The screen would refresh with the new value of 20. ft for the ceiling height. This or other values on this screen may be changed by repeating the process.

THE USER IS WARNED THAT IT IS CRITICAL TO END EACH ENTRY NUMBER WITH A DECIMAL POINT WHEN A NON-INTEGER NUMBER IS INDICATED (I.E., WHEN THE SCREEN DISPLAY SHOWS A DECIMAL POINT FOR THAT ENTRY). THE USER IS WARNED FURTHER THAT THE CODE WILL ATTEMPT TO RUN WITH ANY SPECIFIED INPUT FILE, AND THAT IT WILL NOT DISTINGUISH BETWEEN REALISTIC AND UNREALISTIC INPUT VALUES.

Option 6 HEIGHT TO BOTTOM OF CURTAIN of the room-properties menu is used to define the height above the floor of the bottom of the curtain. As can be seen, in the default data this is chosen as 15. ft. When this height is chosen to be identical to the ceiling height, the user will always define the very special idealized simulation associated with an extensive, unconfined-ceiling fire scenario (i.e., by whatever means, it is assumed that the flow of the ceiling jet is extracted from the compartment at the extremities of the ceiling). Under such a simulation, an upper layer never develops in the compartment. The lower ceiling surface and fusible links will be submerged in and respond to an unconfined ceiling jet environment which is unaffected by layer growth. This idealized fire scenario, involving the unconfined ceiling, is the one used, for example, in [5] to simulate ceiling response and in [6] and [7] to simulate sprinkler response.

Choice of some options on a menu, such as Option 4 NUMBER OF VENTS, ETC. of the room-properties menu, will lead to a subsequent display/requirement of additional associated input data. Menu options requiring multiple-entries are indicated by use of "ETC." In the case of Option 4 NUMBER OF VENTS, ETC., three values will be involved for each vent or group-of-vents actuated by a fusible link. As indicated above under Option 4 NUMBER OF VENTS, ETC., the default data describe a scenario with two vents or groups-of-vents.

Now choose Option 4 NUMBER OF VENTS, ETC. to review and modify the default input data associated with these two vents or group-of-vents. Enter 4 [ret]. The following is displayed on the screen:

```
VENT NO.=    1 FUSIBLE LINK =    2 VENT AREA =       96.00000 FT2
VENT NO.=    2 FUSIBLE LINK =    3 VENT AREA =       96.00000 FT2

ENTER 6 TO REMOVE A VENT
ENTER VENT NO., LINK NO., AND VENT AREA (FT2) TO ADD OR MODIFY A VENT
MAXIMUM NO. OF VENTS IS 5
ENTER 0 TO RETURN TO THE MENU
```

This display indicates that the two simulated vents or group-of-vents are numbered 1 (VENT NO.= 1) and 2 (VENT NO.= 2), that these are actuated by fusible links numbered 2 (FUSIBLE LINK = 2) and 3 (FUSIBLE LINK = 3),

respectively, and that each of the two vents or groups-of-vents have a total area of 96. ft^2 (VENT AREA = 96.00000 FT2).

In the default fire scenario it would be of interest to study the effect of ganging the operation of all of the four vents (total area 192. ft^2) to fusing of the closest vent link. To do so it would be necessary to first remove vent number 2, as identified in the above menu, and then to modify the area of vent number 1.

To remove vent number 2 enter 6 [ret]. The following is now displayed on the screen:

```
ENTER NUMBER OF VENT TO BE ELIMINATED
ENTER 0 TO RETURN TO MENU
```

Now enter 2 [ret]. This completes removal of vent 2, with the following revised display on the screen:

```
VENT NO.=    1 FUSIBLE LINK =    2 VENT AREA =       96.00000 FT2

ENTER 6 TO REMOVE A VENT
ENTER VENT NO., LINK NO., AND VENT AREA (FT2) TO ADD OR MODIFY A VENT
MAXIMUM NO. OF VENTS IS 5
ENTER 0 TO RETURN TO THE MENU
```

Now modify the characteristics of vent number 1. To do this enter 1 [ret], 2 [ret], 192. [ret]. The screen will now display:

```
VENT NO.=    1 FUSIBLE LINK =    2 VENT AREA =      192.00000 FT2

ENTER 6 TO REMOVE A VENT
ENTER VENT NO., LINK NO., AND VENT AREA (FT2) TO ADD OR MODIFY A VENT
MAXIMUM NO. OF VENTS IS 5
ENTER 0 TO RETURN TO THE MENU
```

To add or reimplement vent number 2, actuated by link number 3, and of area 96. ft^2, enter 2 [ret], 3[ret], 96. [ret]. Now return to the original default scenario by bringing the area of vent number 1 back to its original 96. ft^2 value; enter 1[ret], 2 [ret], and 96. [ret].

The user may now continue to modify or add additional ceiling vents or return to the room-properties menu by entering 0 [ret]. If the user tries to associate a vent with a link not yet entered in the program, the code will warn the user, give the maximum number of links available in the present data set, and request a new link value. If the user deletes a link that is

assigned to a vent, the code will assign the link with the next smallest number to that vent. The best method for assigning vents to links is to first use Option 4 FUSIBLE LINK PROPERTIES of the base menu (to be discussed in Section 4.4) to assign the link parameters and then to use Option 1 ROOM PROPERTIES followed by the NUMBER OF VENTS, ETC. option to assign vent properties.

Now return to the room-properties menu by entering 0 [ret], and then to the base menu by entering 0 [ret] again.

With the base menu back on the screen, choose Option 2 PHYSICAL PROPERTIES to review and/or modify the default room-property input data. Enter 2 [ret].

4.2 Physical Properties

When Option 2 PHYSICAL PROPERTIES of the base menu is chosen, the following physical properties menu is displayed:

```
MATERIAL =                  INSULATED DECK (SOLID POLYSTYRENE)
HEAT CONDUCTIVITY =           2.400E-05 (BTU/S LB F)
HEAT CAPACITY =               2.770E-01 (BTU/LB F)
DENSITY =                     6.550E+01 (LB/FT3)

1              80.00000      AMBIENT TEMPERATURE (F)
2               0.50000      MATERIAL THICKNESS (FT)
3      MATERIAL =            INSULATED DECK (SOLID POLYSTYRENE)
0                            CHANGE NOTHING
```

The values in Options 1 and 2 are modified by entering the option number and then the new value.

Now choose Option 3. Enter 3 [ret]. The following menu is displayed:

```
1      CONCRETE
2      BARE METAL DECK
3      INSULATED DECK (SOLID POLYSTYRENE)
4      WOOD
5      OTHER
```

By choosing one of Options 1 through 4 of this menu, the user specifies the material properties of the ceiling according to the table of standard material properties in [8]. When the option number of one of these materials is chosen, the material name, thermal conductivity, heat capacity, and density are displayed on the screen as part of an updated physical properties menu. Now choose Option 5 OTHER. Enter 5 [ret]. The following screen is displayed:

```
ENTER MATERIAL NAME
THERMAL CONDUCTIVITY (BTU/S FT F)
HEAT CAPACITY (BTU/LB F)
DENSITY (LB/FT3)
```

The four indicated inputs are required. After these are entered, the screen returns to an updated physical properties menu.

Now return to the default material, INSULATED DECK (SOLID POLYSTYRENE). To do so enter any arbitrary material name with any three property values (enter MATERIAL [ret], 1. [ret], 1., [ret], 1. [ret]); then choose Option 3 MATERIAL from the menu displayed (enter 3 [ret]); and, from the final menu displayed, choose Option 3 INSULATED DECK (SOLID POLYSTYRENE) (enter 3 [ret]).

Now return to the base menu. Enter 0 [ret]. Choose Option 3 OUTPUT PARAMETERS of the base menu to review and/or modify the default output-parameter data. Enter 3 [ret].

4.3 Output Parameters

When Option 3 OUTPUT PARAMETERS of the base menu is chosen, the following output-parameters menu is displayed:

```
1        400.000000        FINAL TIME (S)
2         30.000000        OUTPUT INTERVAL (S)
0                          CHANGE NOTHING
```

The FINAL TIME represents the ending time of the calculation. The OUTPUT INTERVAL controls the time interval between successive outputs of the calculation results. All times are in seconds. For example, assume that it is desired to run a fire scenario for 500. s with an output of results each 10. s. Then first choose Option 1 with a value of 500. (enter 1 [ret], 500. [ret]), and then Option 2 with a value of 10. (enter 2 [ret], 10. [ret]). The following revised output-parameters menu is displayed:

```
1        500.000000        FINAL TIME (S)
2         10.000000        OUTPUT INTERVAL (S)
0                          CHANGE NOTHING
```

Return to the original default output-parameters menu by entering 1 [ret], 400. [ret], followed by 2 [ret], 30. [ret].

Now return to the base menu from the output-parameters menu by entering 0 [ret].

With the base menu back on the screen, choose Option 4 FUSIBLE LINK PROPERTIES to review and/or modify the default fusible-link-properties data. Enter 4 [ret].

4.4 Fusible Link Properties

When Option 4 FUSIBLE LINK PROPERTIES of the base menu is chosen, the following fusible-link-properties menu is displayed:

```
TO ADD OR CHANGE A LINK,
ENTER LINK NO., RADIUS (FT), DISTANCE BELOW CEILING (FT),
RTI (SQRT[FT S]), AND FUSE TEMPERATURE (F).
MAXIMUM NUMBER OF LINKS EQUAL 10.
ENTER 11 TO REMOVE A LINK.
ENTER 0 TO RETURN TO THE MENU.
```

LINK #	RADIUS (FT)	DISTANCE (FT) BELOW CEILING	RTI SQRT(FT S)	FUSE TEMPERATURE (F)
1	6.000	1.000	400.000	165.000
2	21.200	0.300	50.000	165.000
3	44.300	0.300	50.000	165.000

Each fusible link must be assigned a link number (e.g., LINK # = 1), radial position from the plume-ceiling impingement point (e.g., RADIUS = 6.00 FT), ceiling-to-link separation distance (e.g., DISTANCE BELOW CEILING = 1.00 FT), response-time-index (e.g., RTI = 400.00 SQRT[FT S]), and fuse temperature (e.g., FUSE TEMPERATURE = 165.00 F).

Suppose that in the default fire scenario it was desired to simulate the thermal response of the group of (four) sprinkler links second closest to the fire. According to the description of Section 2 and Figure 2, this would be done by adding a fourth link, link number 4, at a radial distance of 13.4 ft, 1.0 ft below the ceiling, with an RTI of 400.0 $[ft \cdot s]^{1/2}$ and a fusion temperature of 165.0 F. To do this enter 4 [ret], 13.4. [ret], 1. [ret], 400. [ret], 165. [ret]. Then the following screen is displayed:

TO ADD OR CHANGE A LINK,
ENTER LINK NO., RADIUS (FT), DISTANCE BELOW CEILING (FT),
RTI (SQRT[FT S]), AND FUSE TEMPERATURE (F).
MAXIMUM NUMBER OF LINKS EQUAL 10.
ENTER 11 TO REMOVE A LINK.
ENTER 0 TO RETURN TO THE MENU.

LINK #	RADIUS (FT)	DISTANCE (FT) BELOW CEILING	RTI SQRT(FT S)	FUSE TEMPERATURE (F)
1	6.000	1.000	400.000	165.000
2	13.400	1.000	400.000	165.000
3	21.200	0.300	50.000	165.000
4	44.300	0.300	50.000	165.000

Note that the new link, which was entered as link number 4, was sorted automatically into the list of the original three links and that all four links were renumbered according to radial distance from the fire. The original link-vent assignments are preserved in this operation. Hence, the user need not return to Option 4, NUMBER OF VENTS, ETC., unless it is desired to reassign link-vent combinations.

A MAXIMUM OF 10 LINK RESPONSES CAN BE SIMULATED IN ANY ONE SIMULATION.

Now remove link number 2 to return to the original default array of links. To do so enter 11 [ret]. The following screen is displayed:

ENTER THE NUMBER OF THE LINK TO BE REMOVED

Enter 2 [ret] to remove link 2.

Now return to the base menu from the fusible-link-properties menu by entering 0 [ret].

With the base menu back on the screen, choose Option 5 FIRE PROPERTIES to review and/or modify the default fire-properties data. Enter 5 [ret].

4.5 Fire Properties

When Option 5 FIRE PROPERTIES from the base menu is chosen, the following fire-properties menu is displayed:

1	2.5	FIRE HEIGHT (FT)
2	330.0	FIRE POWER/AREA (BTU/S FT2), ETC.
3		FIRE OUTPUT AS A FUNCTION OF TIME
0		CHANGE NOTHING

The value associated with Option 1 is the height of the base of the fire above the floor. Change this to 3 ft, for example, by entering 1 [ret] and 3. [ret]. Then return to the default data by entering 1 [ret] and 2.5 [ret].

The value associated with Option 2 is the fire-energy-release rate-per-fire area. It is also possible to consider simulations where the fire area is fixed by specifying a fixed fire diameter. The fire-energy-release rate-per-fire area can be changed, or the fixed fire area-type of specification can be made by choosing Option 2. To do this enter 2 [ret]. This leads to a display of the following menu:

1	WOOD PALLETS,STACK, 5 FT HIGH	330 (BTU/S FT2)
2	CARTONS, COMPARTMENTED, STACKED 15 FT HIGH	200 (BTU/S FT2)
3	PE BOTTLES IN COMPARTMENTED CARTONS 15 FT HIGH	540 (BTU/S FT2)
4	PS JARS IN COMPARTMENTED CARTONS 15 FT HIGH	1300 (BTU/S FT2)
5	GASOLINE	200 (BTU/S FT2)
6	INPUT YOUR OWN VALUE IN (BTU/S FT2)	
7	SPECIFY A CONSTANT DIAMETER FIRE IN FT	
0	CHANGE NOTHING	

Options 1 through 5 of the above menu are for variable-area fires. The Option 1-to-5 constants displayed above on the right are the fire-energy-release rate-per-unit fire area. They are taken from Table 1. If one of these options is chosen, an appropriately-updated fire-properties menu is then displayed on the screen. Option 0 would lead to the return of the original fire-properties menu.

Option 6 allows any other fire-energy-release rate-per-unit fire area of the user's choice.

Option 7 allows the user to specify the diameter of a constant-area fire instead of a energy-release-rate-per-unit-area fire.

Choice of Option 6 or 7 must be followed by entry of the appropriate value. Then an appropriately updated fire-properties menu appears on the screen.

To try Option 7 SPECIFY A CONSTANT DIAMETER FIRE IN FEET, enter 7 [ret]. The following screen is displayed:

ENTER YOUR VALUE FOR FIRE DIAMETER IN FT

Assume the fire diameter is fixed at 5. ft. Enter 5. [ret]. Then the following screen is displayed:

```
1              2.50000      FIRE HEIGHT (FT)
2              5.00000      FIRE DIAMETER (FT), ETC.
3                           FIRE OUTPUT AS A FUNCTION OF TIME
0                           CHANGE NOTHING
```

Now return to the original default fire-properties menu. Enter 2 [ret]. The previous menu will be displayed. In this, choose Option 1 WOOD PALLETS, ... by entering 1 [ret].

Option 3 FIRE OUTPUT AS A FUNCTION OF TIME of the fire-properties menu allows the user to prescribe the fire as a function of time. The prescription involves 1) linear interpolation between adjacent pairs of user-specified points with coordinates (time in s, fire-energy-release rate in BTU/s), and 2) continuation of the fire to arbitrarily large time at the fire-energy-release rate of the last data point.

Now choose Option 3 by entering 3 [ret]. The following screen associated with the default fire-output data is displayed:

```
1    TIME(SEC) =     0.0000   POWER(BTU/S) =      0.00000E+00
2    TIME(SEC) =   100.0000   POWER(BTU/S) =      0.59200E+03
3    TIME(SEC) =   200.0000   POWER(BTU/S) =      0.23670E+04
4    TIME(SEC) =   400.0000   POWER(BTU/S) =      0.94680E+04
5    TIME(SEC) =   600.0000   POWER(BTU/S) =      0.21302E+05
6    TIME(SEC) =   747.0000   POWER(BTU/S) =      0.33000E+05

ENTER DATA POINT NO., TIME (S), AND POWER (BTU/S)
ENTER 11 TO REMOVE A POINT
ENTER 0 TO RETURN TO MENU
```

As discussed in Section 2, with use of the six above data points, the default simulation will estimate the fire's energy-release-rate according to the plot of Figure 3.

Additional data points can be added to the fire-growth simulation by entering the new data-point number, [ret], the time in seconds, [ret], the energy-release-rate in BTU/s, and [ret].

The maximum number of data points permitted is 10. The points may be entered in any order. A sorting routine will order the points by time. One point must correspond to zero time.

As an example of adding an additional data point to the above six, assume that a closer match to the "t-squared" default fire-growth curve was desired between 200. s and 400. s. From Section 2 it can be verified that the fire energy-release rate will be 5325. BTU/s at t = 300. To add this point to the data, thereby forcing the fire-growth curve to pass exactly through the "t-squared" curve at 300 s, enter 7 [ret], 300. [ret], and 5325. [ret]. The following revised screen will be displayed:

```
1     TIME(SEC) =     0.0000   POWER(BTU/S) =      0.00000E+00
2     TIME(SEC) =   100.0000   POWER(BTU/S) =      0.59200E+03
3     TIME(SEC) =   200.0000   POWER(BTU/S) =      0.23670E+04
4     TIME(SEC) =   300.0000   POWER(BTU/S) =      0.53250E+04
5     TIME(SEC) =   400.0000   POWER(BTU/S) =      0.94680E+04
6     TIME(SEC) =   600.0000   POWER(BTU/S) =      0.21302E+05
7     TIME(SEC) =   747.0000   POWER(BTU/S) =      0.33000E+05

ENTER DATA PT. NO., TIME (S), AND POWER (BTU/S)
ENTER 11 TO REMOVE A POINT
ENTER 0 TO RETURN TO MENU
```

Note that the revised point, which was entered as point number 7, has been resorted into the original array of data points and that all points have been renumbered appropriately.

Now remove the point just added (which is now point number 4). First enter 11 [ret]. Then the following screen is displayed:

```
ENTER THE NUMBER OF THE DATA POINT TO BE REMOVED
```

Now enter 4 [ret]. This brings the fire-growth-simulation data back to the original default set of values.

Now return to the fire-properties menu. Enter 0 [ret]. Then return to the base menu by entering again 0 [ret].

With the base menu back on the screen, it is assumed that imputing of all data required to define the desired fire simulation is complete. Now choose Option 0 NO CHANGES to proceed to the file-status menu. Enter 0 [ret].

5. File Status - Running the Code

When Option 0 NO CHANGES of the base menu is chosen, the following file-status menu is displayed:

```
1       SAVE THE FILE AND RUN THE CODE
2       SAVE THE FILE BUT DONT RUN THE CODE
3       DONT SAVE THE FILE BUT RUN THE CODE
4       ABORT THE CALCULATION
```

If one of the save options is selected, the user will be asked to supply a file name to designate the file where the newly generated input data is to be saved. The program will automatically create the new file. File names may be

as long as 8 characters and should have a common extender such as .DAT, example MYFILE.DAT. The maximum length that may be used for the total length of input or output files is 25 characters. For example, C:\SUBDIRECT\FILENAME.DAT would allow a file named FILENAME.DAT to be read from the subdirectory SUBDIRECT on the C drive. To read a file from a floppy disk in the A drive, use A:FILENAME.DAT. If Option 4 is chosen the program will end without any file being saved.

A request for an output file name will appear on the screen. File names may be as long as 8 characters and should have an extender such as .OUT such that the output files can easily be recognized. To output a file to a floppy disk in the A drive, name the file A:FILENAME.OUT. To output a file to a subdirectory other than the one which is resident to the program, use C:\SUBDIRECT\FILENAME.OUT for the subdirectory SUBDIRECT.

Once the output file has been designated, the program will begin to execute. The statement PROGRAM RUNNING will appear on the screen. Each time the program writes to the output file, a statement such as T = 3.0000E01 S will appear on the screen to provide the user with the present output time.

6. The Output Variables and the Output Options

The program generates two separate output files. An example of the first output file is appended at the end of this document. This file is named by the user and consists of a listing of the input data plus all the relevant output variables in a format where the output units are specified and the meaning of all but three of the output variables are clearly specified. These latter variables are TSL, QB, and QT which are the temperature of the ceiling inside the enclosure, the net heat transfer flux to the bottom surface of the ceiling, and the net heat transfer flux to the top surface of the ceiling. The variables are output as a function of radius with R = 0 being the center of the fire plume projected on the ceiling. Other abbreviations include LYR TEMP, LYR HT, LYR MASS, JET VELOCITY, and JET TEMP which are the upper layer (layer adjacent to the ceiling) temperature, height of the upper layer interface above the floor, mass of gas in the layer, ceiling jet velocity and temperature at the position of each fusible link. The VENT AREA is the total area of roof vents open at the time of output.

The second output file, GRAPH.OUT, is used by the graphics program, GRAPH. GRAPH is a Fortran program which makes use of a graphics software package developed in [9, 10] to produce graphical output of selected output variables. To use the graphics program, the file GRAPH.OUT must be in the same directory as the program, GRAPH. GRAPH is a menu driven program which provides the user with the ability to plot two sets of variables on the PC screen. An option exists which permits the user to print the plots from the screen to a printer. If the user has an attached EPSON-compatible printer, enter 'e' to produce a plot using the printer. If the user wishes to generate a PostScript file for use on a laser printer, enter 'p' and provide a file name when the file name prompt appears in the upper left hand corner of the graph. To exit to screen mode from the graphics mode, enter 'c'. The file GRAPH.OUT will be destroyed each time the code LAVENT is run. If the user wishes to save the graphics

file, it must be copied using the DOS copy command into another file with a different file name.

To demonstrate the use of GRAPH, start the program by entering 'graph' [ret]. GRAPH will read in the graphics output file GRAPH.OUT and the following screen will be displayed:

ENTER 0 TO PLOT POINTS, ENTER 1 TO PLOT AND CONNECT POINTS

The graphics presented in Figures 5 - 9 were done with GRAPH using option 0. Enter 0 [ret] and the following graphics menu is displayed:

ENTER THE X AND Y VARIABLES FOR THE DESIRED TWO GRAPHS
1 TIME
2 LAYER TEMPERATURE
3 LAYER HEIGHT
4 LAYER MASS
5 FIRE OUTPUT
6 CEILING VENT AREA
7 PLUME FLOW
8 LINK TEMPERATURE
9 JET VELOCITY AT LINK
10 JET TEMPERATURE AT LINK

Two plots can be studied on a single screen. For example, from the default simulation assume that displays of the plots of Figure 5 and 6, LAYER HEIGHT vs TIME and LAYER TEMPERATURE vs TIME, respectively, are desired. Then enter 1 [ret], 3 [ret], 1 [ret], and 2 [ret]. The program will respond with the prompt:

ENTER THE TITLES FOR THE TWO GRAPHS, 16 CHARACTERS MAX.

The user might choose titles which would identify particular cases such as LY HT RUN 100 [ret] and LY TEMP RUN 100 [ret]. If the title is chosen to be longer than 16 characters, it will be truncated to 16 characters. After the titles have been entered the program will respond with:

ENTER 1 FOR DEFAULT SCALING, 2 FOR USER SCALING.

If the user chooses option 1, the desired plots will appear on the screen with an internal scaling for the X and Y axis of each graph. If the user chooses option 2, the program will respond with the following prompt:

ENTER THE MINIMUM AND MAXIMUM VALUES FOR THE X AND Y AXIS
OF EACH GRAPH. ENTER 0 FOR THE MINIMUM AND MAXIMUM VALUES
OF EACH AXIS WHERE DEFAULT SCALING IS DESIRED. FOR EXAMPLE,
VALUES SHOULD BE ENTERED AS 0.,100.,0.,200.,10.,50.,20.,100. [RET]
FOR X1(0-100), Y1(0-200), X2(10-50), Y2(20-100).

Use of this option allows a number of different cases to be compared using similar values for the X and Y axis of each graph. All eight numbers must be entered and separated with commas before entering [ret]. Once the entry is made, the plots will appear on the screen. Note that this option permits a mixture of default scaling and user specified scaling.

Once a pair of plots are displayed on the screen, the user would have the choice of entering 'p' or 'e', to obtain a hard-copy plot of the graphs, or of entering 'c' to exit the graphics mode.

To plot a second pair of graphs, the user would exit the graphics mode by entering 'c' and then repeat the above process by entering 'graph' [ret], etc.

If the user selects plots which involve variables defined by Options 8, 9, or 10, then, following the entry 8 [ret], 9 [ret] or 10 [ret], the following prompt for identifying the desired link number (in the default simulation with 3 simulated links) will be displayed immediately:

ENTER LINK NUMBER, MAXIMUM NUMBER = 3

The user then enters the desired link number followed by [ret], and continues entering the remaining input data which define the desired plots.

As an example of generating link-related plots, consider displaying the pair of plots LINK TEMPERATURE vs TIME and JET VELOCITY AT LINK vs TIME for link number 3 in the default simulation. First enter 1 [ret] (for TIME on the X axis) and 8 [ret](for LINK TEMPERATURE on the Y axis). At this point, "ENTER LINK NUMBER ..." would be displayed on the screen. Continue by entering 3 [ret] (for link number 3). This would complete the data entry for the first of the two plots. For the second plot enter 1 [ret] (for TIME on the X axis) and 9 [ret] (for LINK TEMPERATURE on the Y axis). At this point, "ENTER LINK NUMBER ..." would be displayed a second time. Then conclude data input for the pair of plots by entering 3 [ret] (for link number 3). At this point the desired pair of plots would be displayed on the screen.

7. An Example Simulation - The Default Case

This section presents and reviews briefly the simulation of the default case.

The tabular output of the default simulation is presented in Figure 4. Plots of the layer-interface height and of the layer temperature as functions of time are plotted in Figures 5 and 6, respectively. Plots of the thermal

response of the two pairs of vent links and the pair of sprinkler links closest to the fire are presented in Figures 7 - 9, respectively

From Figures 4 and 7 - 9 it is seen that the sequence of link fusing (at 165 F) is predicted to be the near pair of vents at 189 s, the far pair of vents at 268 s, and the pair of closest sprinklers at 283 s. Although the sprinkler links are closer to the fire than any of the vent links, and although all links have the same fuse temperatures, the simulation predicts that the sprinkler links fuse after all of the vent links. There are two reasons for this. First, the RTI of the sprinkler links are larger than those of the vent links and, therefore, slower to respond thermally. Second, the two sprinkler links simulated are far enough from the ceiling as to be below the peak temperature of the ceiling jet which is relatively thin at the 6 ft radial position (see the lower sketch of Figure 1).

The effect on layer growth of fusing of the two pair of vent links and opening of their corresponding vents at 189 s and 268 s can be noted in Figure 5. Note that the opening of the first pair of vents effectively stops the rate-of-increase of layer thickness and opening of the second pair of vents leads to a relatively rapid rate-of-decrease in the layer thickness. All of this is of course occurring at times when the energy-release-rate of the fire is growing rapidly.

As can be seen in Figure 5, up to the 400 s of simulation time the smoke is still contained in the original curtained compartment and has not "spilled over" to adjacent spaces. From this figure it appears that with no venting, the layer would have dropped below the bottom of the draft curtains prior to fusing of the first sprinkler links. This could be confirmed with a second simulation run of LAVENT, where all vent action was removed from the default data.

8. Acknowledgements

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9. References

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APPENDIX - Solver Parameters

If the code is not able to obtain a solution for a particular application or is taking an inordinate amount of time to produce the solution, there are a number of variations of the default solver inputs which may resolve the problem.

Start the input part of the program get to the base menu. Then choose Option 6 SOLVER PARAMETERS. The following input options menu will be displayed:

1	0.6500E+00	GAUSS-SEIDEL RELAXATION
2	0.1000E-04	DIFF EQ SOLVER TOLERANCE
3	0.1000E-04	GAUSS-SEIDEL TOLERANCE
4	2.000000	FLUX UPDATE INTERVAL (S)
5		CHANGE NOTHING

The solvers used in this code consist of a differential equation solver DDRIVE2, used to solve the set of differential equations associated with the layer and the fusible links, and a Gauss-Seidel/Tridiagonal solver using the Crank-Nicolson formalism to solve the set of partial differential equations associated with the heat conduction calculation for the ceiling. Since two different solvers are being used in the code, there is potential for the solvers to become incompatible with each other, particularly if the upper layer has nearly reached a steady-state temperature but the ceiling is still increasing it's temperature. When this occurs, the differential equation solver will try to take time steps that are too large for the Gauss-Seidel solver to handle and a growing oscillation in the ceiling temperature variable may occur. By reducing the flux-update interval, the growing oscillation may be suppressed. The smaller the flux-update interval, the slower the code will run.

The Gauss-Seidel Relaxation Coefficient may be changed to produce a faster running code or to handle a case that will not run with a different coefficient. Typical values of this coefficient should range between .2 and 1.0.

The tolerances for both solvers may also be changed. Decreasing or increasing these values may provide a faster running code for a given case and by decreasing the value of the tolerances, the accuracy of the calculations may be increased. If the tolerance values are made too small, the code will either run very slowly or not run at all. Suggested tolerances would be in the range of .00001 to .000001.

Table 1. Energy-release-rate per unit area for limited-growth fires in different commodities (from Table 4-1 of [4]).

(PE = polyethylene; PS = polystyrene; PVC = polyvinyl chloride; PP = polypropylene; FRP = Fiberglass-Reinforced Polyester)

Commodity	(Btu/s)/ft^2 of Floor Area
1. Wood pallets, stack 1 1/2 ft high (6-12% moisture)	110
2. Wood pallets, stack 5 ft high (6-12% moisture)	330
3. Wood pallets, stack 10 ft high (6-12% moisture)	600
4. Wood pallets, stack 16 ft high (6-12% moisture)	900
5. Mail bags, filled, stored 5 ft high	34
6. Cartons, compartmented, stacked 15 ft high	200
7. PE letter trays, filled, stacked 5 ft high on a cart	740
8. PE trash barrels in cartons, stacked 15 ft high	240
9. FRP shower stalls in cartons, stacked 15 ft high	110
10. PE bottles packed in Item 6	540
11. PE bottles in cartons, stacked 15 ft high	170
12. PU insulation board, rigid foam, stacked 14 ft high	160
13. PS jars packed in Item 6	1,300
14. PS tubs nested in cartons, stacked 14 ft high	440
15. PS toy parts in cartons, stacked 15 ft high	170
16. PS insulation board, rigid foam, stacked 14 ft high	280
17. PVC bottles packed in Item 6	300
18. PP tubs packed in Item 6	370
19. PP and PE film in rolls, stacked 14 ft high	540
20. Methyl alcohol	55
21. Gasoline	200
22. Kerosene	200
23. Diesel oil	170

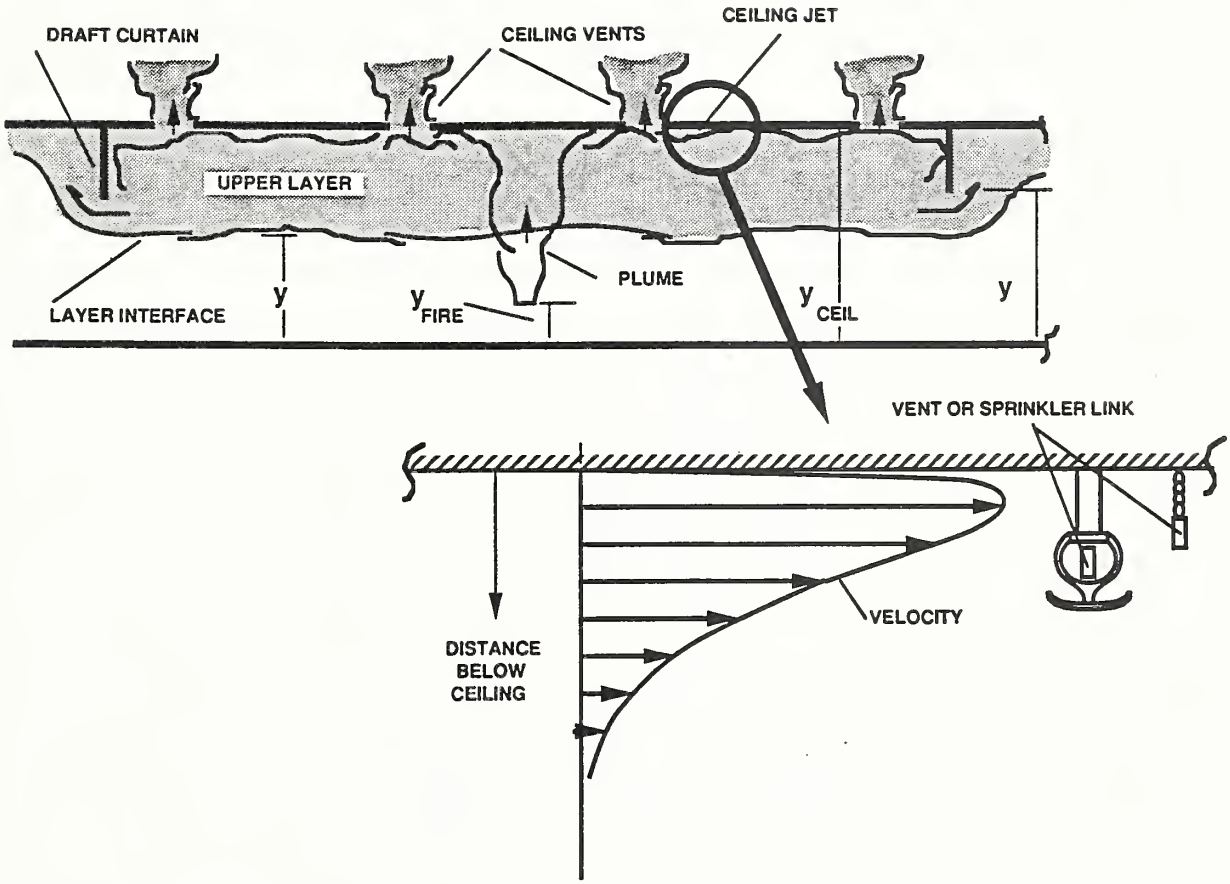

Figure 1. Fire in a building with draft curtains and fusible-link-actuated ceiling vents and sprinklers.

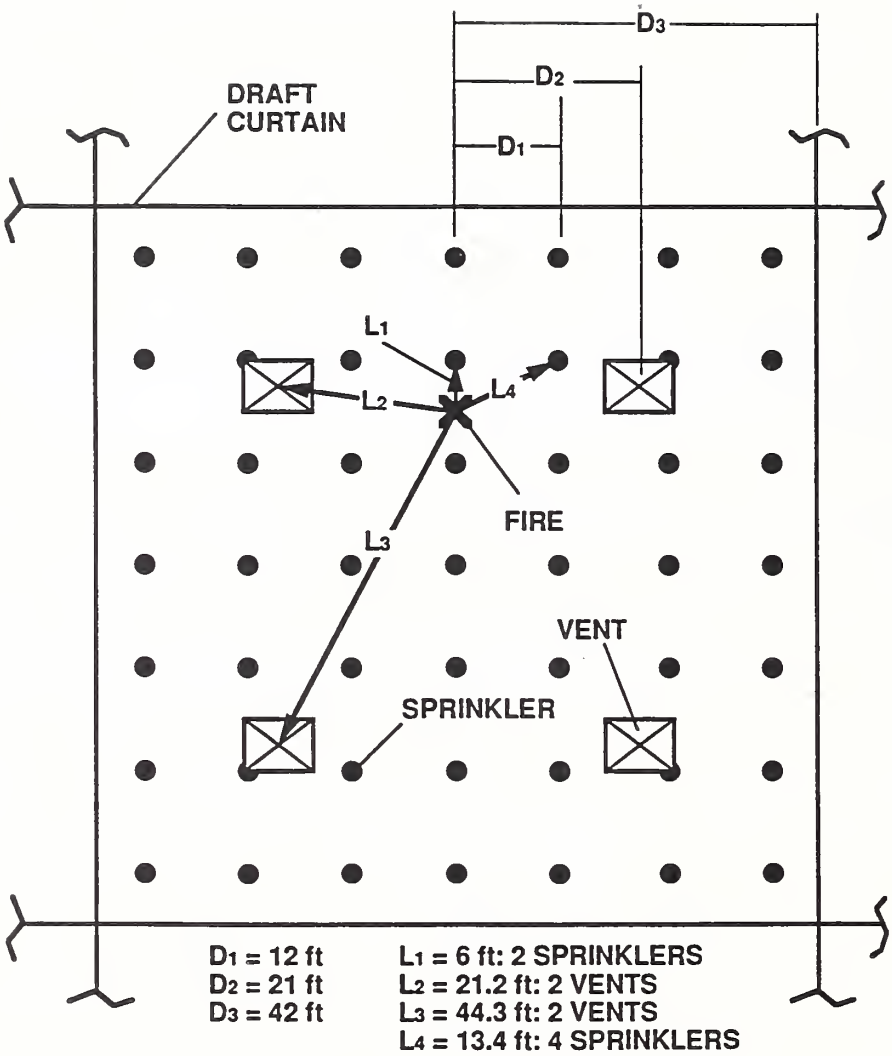

Figure 2. Vent and sprinkler spacing and fire location for the default simulation.

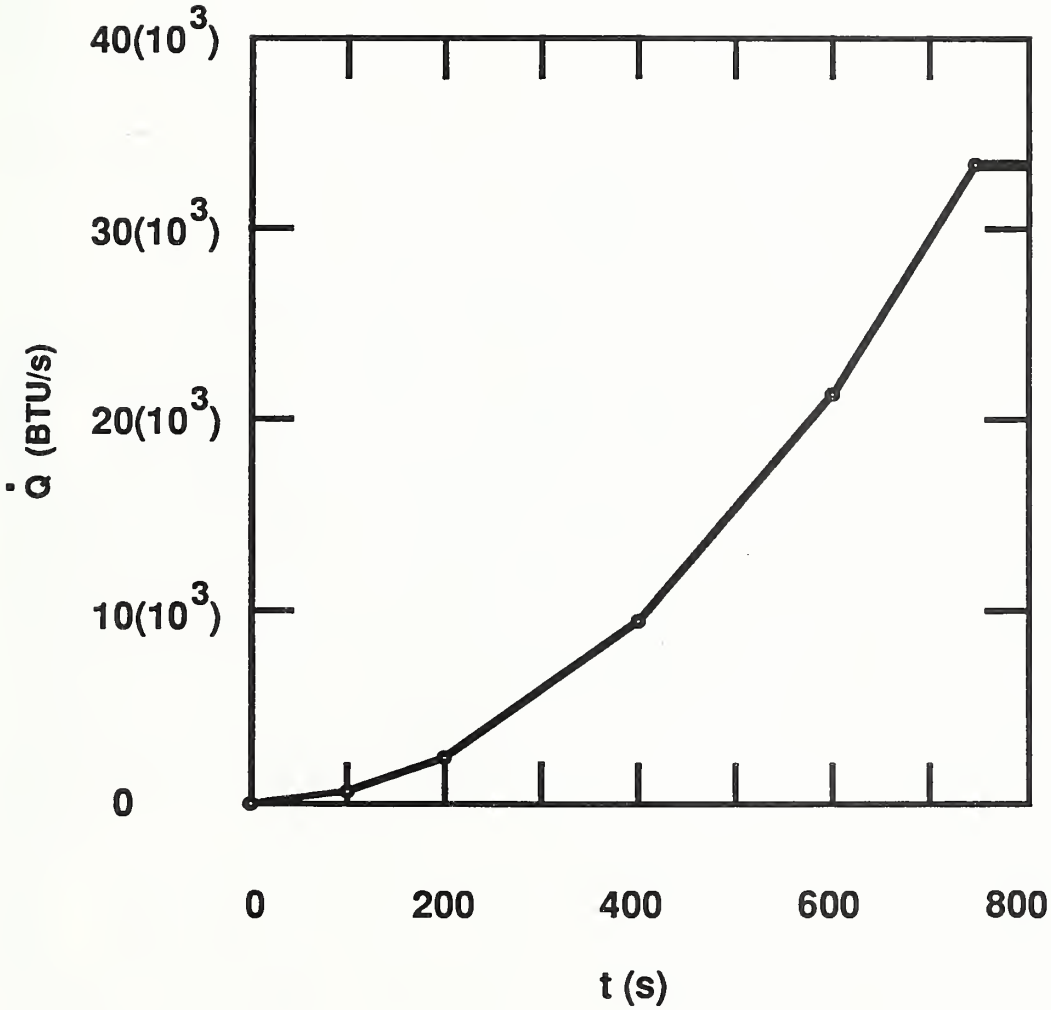

Figure 3. Energy-release-rate vs time for the fire of the default simulation.

```
CEILING HEIGHT =                    30.0 FT
ROOM LENGTH =                       84.0 FT
ROOM WIDTH =                        84.0 FT
CURTAIN LENGTH =                   336.0 FT
CURTAIN HEIGHT =                    15.0 FT
MATERIAL =                         INSULATED METAL DECK
CEILING CONDUCTIVITY =        .240E-04 BTU/FT F S
       CEILING DENSITY =      .277E+00 LB/FT3
CEILING HEAT CAPACITY  =      .655E+02 BTU/LB F
CEILING THICKNESS =           .500E+00 FT
FIRE HEIGHT =                       2.5 FT
FIRE POWER/AREA =            0.3300E+03 BTU/FT2 S

LINK NO =  1 RADIUS =     6.0 FT    DIST CEILING =     1.0 FT
 RTI=  400.00 SQRT FUSION TEMPERATURE FOR LINK =   165.00 K
LINK NO =  2 RADIUS =    21.2 FT    DIST CEILING =     0.3 FT
 RTI=   50.00 SQRT FUSION TEMPERATURE FOR LINK =   165.00 K
LINK NO =  3 RADIUS =    44.3 FT    DIST CEILING =     0.3 FT
 RTI=   50.00 SQRT FUSION TEMPERATURE FOR LINK =   165.00 K
VENT =   1   VENT AREA =     96.0 FT2          LINK CONTROLLING VENT =   2
VENT =   2   VENT AREA =     96.0 FT2          LINK CONTROLLING VENT =   3
TIME (S)=    0.000 LYR TEMP (F)=    80.0 LYR HT (FT)=   30.00 LYR MASS (LB)= 0.000E+00
FIRE OUTPUT (BTU/S)=  0.0000E+00 VENT AREA (FT2)=      0.00
LINK =  1 LINK TEMP (F)=   80.00 JET VELOCITY (FT/S)=     0.000 JET TEMP (F) =     80.0
LINK =  2 LINK TEMP (F)=   80.00 JET VELOCITY (FT/S)=     0.000 JET TEMP (F) =     80.0
LINK =  3 LINK TEMP (F)=   80.00 JET VELOCITY (FT/S)=     0.000 JET TEMP (F) =     80.0
R (FT)=    0.00 TSL (F)=    80.0 QB (BTU/FT2 S)= 0.000E+00 QT (BTU/FT2 S)= 0.000E+00
R (FT)=    5.64 TSL (F)=    80.0 QB (BTU/FT2 S)= 0.000E+00 QT (BTU/FT2 S)= 0.000E+00
R (FT)=   11.28 TSL (F)=    80.0 QB (BTU/FT2 S)= 0.000E+00 QT (BTU/FT2 S)= 0.000E+00
R (FT)=   16.92 TSL (F)=    80.0 QB (BTU/FT2 S)= 0.000E+00 QT (BTU/FT2 S)= 0.000E+00
R (FT)=   22.56 TSL (F)=    80.0 QB (BTU/FT2 S)= 0.000E+00 QT (BTU/FT2 S)= 0.000E+00
R (FT)=   28.20 TSL (F)=    80.0 QB (BTU/FT2 S)= 0.000E+00 QT (BTU/FT2 S)= 0.000E+00
R (FT)=   33.85 TSL (F)=    80.0 QB (BTU/FT2 S)= 0.000E+00 QT (BTU/FT2 S)= 0.000E+00
R (FT)=   39.49 TSL (F)=    80.0 QB (BTU/FT2 S)= 0.000E+00 QT (BTU/FT2 S)= 0.000E+00
R (FT)=   45.13 TSL (F)=    80.0 QB (BTU/FT2 S)= 0.000E+00 QT (BTU/FT2 S)= 0.000E+00
R (FT)=   50.77 TSL (F)=    80.0 QB (BTU/FT2 S)= 0.000E+00 QT (BTU/FT2 S)= 0.000E+00
R (FT)=   56.41 TSL (F)=    80.0 QB (BTU/FT2 S)= 0.000E+00 QT (BTU/FT2 S)= 0.000E+00
R (FT)=   62.05 TSL (F)=    80.0 QB (BTU/FT2 S)= 0.000E+00 QT (BTU/FT2 S)= 0.000E+00
TIME (S)=   30.000 LYR TEMP (F)=    89.5 LYR HT (FT)=   28.90 LYR MASS (LB)= 0.562E+03
FIRE OUTPUT (BTU/S)=  0.1776E+03 VENT AREA (FT2)=      0.00
LINK =  1 LINK TEMP (F)=   80.79 JET VELOCITY (FT/S)=     1.988 JET TEMP (F) =     94.6
LINK =  2 LINK TEMP (F)=   85.26 JET VELOCITY (FT/S)=     2.177 JET TEMP (F) =     94.7
LINK =  3 LINK TEMP (F)=   81.81 JET VELOCITY (FT/S)=     0.915 JET TEMP (F) =     87.2
R (FT)=    0.00 TSL (F)=    84.1 QB (BTU/FT2 S)= 0.287E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=    5.64 TSL (F)=    82.6 QB (BTU/FT2 S)= 0.186E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   11.28 TSL (F)=    81.8 QB (BTU/FT2 S)= 0.130E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   16.92 TSL (F)=    81.2 QB (BTU/FT2 S)= 0.892E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   22.56 TSL (F)=    80.9 QB (BTU/FT2 S)= 0.641E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   28.20 TSL (F)=    80.6 QB (BTU/FT2 S)= 0.481E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   33.85 TSL (F)=    80.5 QB (BTU/FT2 S)= 0.373E-02 QT (BTU/FT2 S)= 0.847E-18
```

Figure 4. (Page 1 of 6 pages). Tabular format for the output - the default simulation.

```
R (FT)=   39.49 TSL (F)=    80.4 QB (BTU/FT2 S)= 0.298E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   45.13 TSL (F)=    80.3 QB (BTU/FT2 S)= 0.244E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   50.77 TSL (F)=    80.3 QB (BTU/FT2 S)= 0.205E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   56.41 TSL (F)=    80.2 QB (BTU/FT2 S)= 0.174E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   62.05 TSL (F)=    80.2 QB (BTU/FT2 S)= 0.151E-02 QT (BTU/FT2 S)= 0.847E-18
TIME (S)=   60.000 LYR TEMP (F)=    96.2 LYR HT (FT)=   27.34 LYR MASS (LB)= 0.134E+04
FIRE OUTPUT (BTU/S)=  0.3552E+03 VENT AREA (FT2)=      0.00
LINK =  1 LINK TEMP (F)=   82.84 JET VELOCITY (FT/S)=     2.548 JET TEMP (F) =    104.5
LINK =  2 LINK TEMP (F)=   94.79 JET VELOCITY (FT/S)=     2.781 JET TEMP (F) =    105.0
LINK =  3 LINK TEMP (F)=   85.66 JET VELOCITY (FT/S)=     1.169 JET TEMP (F) =     92.5
R (FT)=    0.00 TSL (F)=    91.8 QB (BTU/FT2 S)= 0.480E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=    5.64 TSL (F)=    87.8 QB (BTU/FT2 S)= 0.331E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   11.28 TSL (F)=    85.5 QB (BTU/FT2 S)= 0.237E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   16.92 TSL (F)=    83.8 QB (BTU/FT2 S)= 0.166E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   22.56 TSL (F)=    82.8 QB (BTU/FT2 S)= 0.120E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   28.20 TSL (F)=    82.1 QB (BTU/FT2 S)= 0.909E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   33.85 TSL (F)=    81.6 QB (BTU/FT2 S)= 0.709E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   39.49 TSL (F)=    81.3 QB (BTU/FT2 S)= 0.568E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   45.13 TSL (F)=    81.1 QB (BTU/FT2 S)= 0.467E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   50.77 TSL (F)=    80.9 QB (BTU/FT2 S)= 0.391E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   56.41 TSL (F)=    80.8 QB (BTU/FT2 S)= 0.334E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   62.05 TSL (F)=    80.7 QB (BTU/FT2 S)= 0.290E-02 QT (BTU/FT2 S)= 0.847E-18
TIME (S)=   90.000 LYR TEMP (F)=   102.8 LYR HT (FT)=   25.65 LYR MASS (LB)= 0.216E+04
FIRE OUTPUT (BTU/S)=  0.5328E+03 VENT AREA (FT2)=      0.00
LINK =  1 LINK TEMP (F)=   85.95 JET VELOCITY (FT/S)=     2.976 JET TEMP (F) =    113.9
LINK =  2 LINK TEMP (F)=  105.10 JET VELOCITY (FT/S)=     3.239 JET TEMP (F) =    114.7
LINK =  3 LINK TEMP (F)=   90.46 JET VELOCITY (FT/S)=     1.361 JET TEMP (F) =     97.7
R (FT)=    0.00 TSL (F)=   100.8 QB (BTU/FT2 S)= 0.643E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=    5.64 TSL (F)=    94.3 QB (BTU/FT2 S)= 0.460E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   11.28 TSL (F)=    90.3 QB (BTU/FT2 S)= 0.336E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   16.92 TSL (F)=    87.2 QB (BTU/FT2 S)= 0.238E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   22.56 TSL (F)=    85.2 QB (BTU/FT2 S)= 0.174E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   28.20 TSL (F)=    84.0 QB (BTU/FT2 S)= 0.132E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   33.85 TSL (F)=    83.1 QB (BTU/FT2 S)= 0.104E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   39.49 TSL (F)=    82.5 QB (BTU/FT2 S)= 0.834E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   45.13 TSL (F)=    82.0 QB (BTU/FT2 S)= 0.687E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   50.77 TSL (F)=    81.7 QB (BTU/FT2 S)= 0.578E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   56.41 TSL (F)=    81.5 QB (BTU/FT2 S)= 0.495E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   62.05 TSL (F)=    81.3 QB (BTU/FT2 S)= 0.430E-02 QT (BTU/FT2 S)= 0.847E-18
TIME (S)=  120.000 LYR TEMP (F)=   111.1 LYR HT (FT)=   23.86 LYR MASS (LB)= 0.301E+04
FIRE OUTPUT (BTU/S)=  0.9470E+03 VENT AREA (FT2)=      0.00
LINK =  1 LINK TEMP (F)=   90.39 JET VELOCITY (FT/S)=     3.792 JET TEMP (F) =    128.6
LINK =  2 LINK TEMP (F)=  117.49 JET VELOCITY (FT/S)=     4.108 JET TEMP (F) =    130.6
LINK =  3 LINK TEMP (F)=   96.35 JET VELOCITY (FT/S)=     1.726 JET TEMP (F) =    105.6
R (FT)=    0.00 TSL (F)=   113.3 QB (BTU/FT2 S)= 0.107E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=    5.64 TSL (F)=   103.7 QB (BTU/FT2 S)= 0.786E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   11.28 TSL (F)=    97.2 QB (BTU/FT2 S)= 0.576E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   16.92 TSL (F)=    92.1 QB (BTU/FT2 S)= 0.407E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   22.56 TSL (F)=    88.8 QB (BTU/FT2 S)= 0.298E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   28.20 TSL (F)=    86.7 QB (BTU/FT2 S)= 0.226E-01 QT (BTU/FT2 S)= 0.847E-18
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Figure 4. (Page 2 of 6 pages). Tabular format for the output - the default simulation.

```
R (FT)=   33.85 TSL (F)=    85.2 QB (BTU/FT2 S)= 0.176E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   39.49 TSL (F)=    84.2 QB (BTU/FT2 S)= 0.141E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   45.13 TSL (F)=    83.5 QB (BTU/FT2 S)= 0.116E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   50.77 TSL (F)=    82.9 QB (BTU/FT2 S)= 0.973E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   56.41 TSL (F)=    82.5 QB (BTU/FT2 S)= 0.831E-02 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   62.05 TSL (F)=    82.2 QB (BTU/FT2 S)= 0.721E-02 QT (BTU/FT2 S)= 0.847E-18
TIME (S)=  150.000 LYR TEMP (F)=   123.9 LYR HT (FT)=   21.86 LYR MASS (LB)= 0.391E+04
FIRE OUTPUT (BTU/S)=  0.1479E+04 VENT AREA (FT2)=      0.00
LINK =  1 LINK TEMP (F)=   97.25 JET VELOCITY (FT/S)=     4.518 JET TEMP (F) =    148.4
LINK =  2 LINK TEMP (F)=  136.11 JET VELOCITY (FT/S)=     4.876 JET TEMP (F) =    151.7
LINK =  3 LINK TEMP (F)=  105.03 JET VELOCITY (FT/S)=     2.049 JET TEMP (F) =    116.6
R (FT)=    0.00 TSL (F)=   133.5 QB (BTU/FT2 S)= 0.152E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=    5.64 TSL (F)=   119.1 QB (BTU/FT2 S)= 0.115E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   11.28 TSL (F)=   108.7 QB (BTU/FT2 S)= 0.859E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   16.92 TSL (F)=   100.3 QB (BTU/FT2 S)= 0.615E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   22.56 TSL (F)=    94.9 QB (BTU/FT2 S)= 0.453E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   28.20 TSL (F)=    91.3 QB (BTU/FT2 S)= 0.344E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   33.85 TSL (F)=    88.8 QB (BTU/FT2 S)= 0.270E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   39.49 TSL (F)=    87.1 QB (BTU/FT2 S)= 0.217E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   45.13 TSL (F)=    85.8 QB (BTU/FT2 S)= 0.178E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   50.77 TSL (F)=    84.9 QB (BTU/FT2 S)= 0.150E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   56.41 TSL (F)=    84.2 QB (BTU/FT2 S)= 0.128E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   62.05 TSL (F)=    83.6 QB (BTU/FT2 S)= 0.111E-01 QT (BTU/FT2 S)= 0.847E-18
TIME (S)=  180.000 LYR TEMP (F)=   139.4 LYR HT (FT)=   19.78 LYR MASS (LB)= 0.477E+04
FIRE OUTPUT (BTU/S)=  0.2012E+04 VENT AREA (FT2)=      0.00
LINK =  1 LINK TEMP (F)=  106.73 JET VELOCITY (FT/S)=     5.097 JET TEMP (F) =    170.6
LINK =  2 LINK TEMP (F)=  158.26 JET VELOCITY (FT/S)=     5.485 JET TEMP (F) =    174.9
LINK =  3 LINK TEMP (F)=  116.09 JET VELOCITY (FT/S)=     2.305 JET TEMP (F) =    129.3
R (FT)=    0.00 TSL (F)=   157.2 QB (BTU/FT2 S)= 0.193E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=    5.64 TSL (F)=   137.7 QB (BTU/FT2 S)= 0.149E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   11.28 TSL (F)=   122.9 QB (BTU/FT2 S)= 0.113E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   16.92 TSL (F)=   110.7 QB (BTU/FT2 S)= 0.816E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   22.56 TSL (F)=   102.6 QB (BTU/FT2 S)= 0.606E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   28.20 TSL (F)=    97.2 QB (BTU/FT2 S)= 0.464E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   33.85 TSL (F)=    93.5 QB (BTU/FT2 S)= 0.366E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   39.49 TSL (F)=    90.8 QB (BTU/FT2 S)= 0.295E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   45.13 TSL (F)=    88.9 QB (BTU/FT2 S)= 0.244E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   50.77 TSL (F)=    87.5 QB (BTU/FT2 S)= 0.206E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   56.41 TSL (F)=    86.4 QB (BTU/FT2 S)= 0.176E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   62.05 TSL (F)=    85.6 QB (BTU/FT2 S)= 0.154E-01 QT (BTU/FT2 S)= 0.847E-18
TIME (S)=  210.000 LYR TEMP (F)=   157.8 LYR HT (FT)=   19.48 LYR MASS (LB)= 0.477E+04
FIRE OUTPUT (BTU/S)=  0.2722E+04 VENT AREA (FT2)=     96.00
LINK =  1 LINK TEMP (F)=  118.85 JET VELOCITY (FT/S)=     5.642 JET TEMP (F) =    196.0
LINK =  2 LINK TEMP (F)=  182.70 JET VELOCITY (FT/S)=     6.055 JET TEMP (F) =    201.4
LINK =  3 LINK TEMP (F)=  129.02 JET VELOCITY (FT/S)=     2.544 JET TEMP (F) =    144.1
TIME LINK    2  OPENS EQUALS     188.5193 (S)
R (FT)=    0.00 TSL (F)=   183.4 QB (BTU/FT2 S)= 0.240E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=    5.64 TSL (F)=   158.7 QB (BTU/FT2 S)= 0.189E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   11.28 TSL (F)=   139.3 QB (BTU/FT2 S)= 0.145E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   16.92 TSL (F)=   122.8 QB (BTU/FT2 S)= 0.107E+00 QT (BTU/FT2 S)= 0.847E-18
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Figure 4. (Page 3 of 6 pages). Tabular format for the output - the default simulation.

```
R (FT)=   22.56 TSL (F)=   111.8 QB (BTU/FT2 S)= 0.798E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   28.20 TSL (F)=   104.3 QB (BTU/FT2 S)= 0.614E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   33.85 TSL (F)=    99.1 QB (BTU/FT2 S)= 0.485E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   39.49 TSL (F)=    95.4 QB (BTU/FT2 S)= 0.393E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   45.13 TSL (F)=    92.7 QB (BTU/FT2 S)= 0.325E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   50.77 TSL (F)=    90.7 QB (BTU/FT2 S)= 0.275E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   56.41 TSL (F)=    89.2 QB (BTU/FT2 S)= 0.236E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   62.05 TSL (F)=    88.0 QB (BTU/FT2 S)= 0.206E-01 QT (BTU/FT2 S)= 0.847E-18
TIME (S)=  240.000 LYR TEMP (F)=   183.6 LYR HT (FT)=   19.68 LYR MASS (LB)= 0.449E+04
FIRE OUTPUT (BTU/S)=  0.3787E+04 VENT AREA (FT2)=     96.00
LINK =  1 LINK TEMP (F)=  134.73 JET VELOCITY (FT/S)=     6.268 JET TEMP (F) =    231.1
LINK =  2 LINK TEMP (F)=  214.57 JET VELOCITY (FT/S)=     6.701 JET TEMP (F) =    237.4
LINK =  3 LINK TEMP (F)=  145.65 JET VELOCITY (FT/S)=     2.816 JET TEMP (F) =    164.4
TIME LINK    2  OPENS EQUALS     188.5193 (S)
R (FT)=    0.00 TSL (F)=   217.9 QB (BTU/FT2 S)= 0.306E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=    5.64 TSL (F)=   186.8 QB (BTU/FT2 S)= 0.245E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   11.28 TSL (F)=   161.5 QB (BTU/FT2 S)= 0.191E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   16.92 TSL (F)=   139.5 QB (BTU/FT2 S)= 0.143E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   22.56 TSL (F)=   124.4 QB (BTU/FT2 S)= 0.108E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   28.20 TSL (F)=   114.1 QB (BTU/FT2 S)= 0.832E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   33.85 TSL (F)=   106.9 QB (BTU/FT2 S)= 0.659E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   39.49 TSL (F)=   101.7 QB (BTU/FT2 S)= 0.535E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   45.13 TSL (F)=    98.0 QB (BTU/FT2 S)= 0.443E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   50.77 TSL (F)=    95.2 QB (BTU/FT2 S)= 0.375E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   56.41 TSL (F)=    93.0 QB (BTU/FT2 S)= 0.322E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   62.05 TSL (F)=    91.3 QB (BTU/FT2 S)= 0.281E-01 QT (BTU/FT2 S)= 0.847E-18
TIME (S)=  270.000 LYR TEMP (F)=   216.0 LYR HT (FT)=   19.96 LYR MASS (LB)= 0.416E+04
FIRE OUTPUT (BTU/S)=  0.4852E+04 VENT AREA (FT2)=    192.00
LINK =  1 LINK TEMP (F)=  155.10 JET VELOCITY (FT/S)=     6.711 JET TEMP (F) =    271.0
LINK =  2 LINK TEMP (F)=  252.61 JET VELOCITY (FT/S)=     7.145 JET TEMP (F) =    277.2
LINK =  3 LINK TEMP (F)=  166.43 JET VELOCITY (FT/S)=     3.002 JET TEMP (F) =    188.0
TIME LINK    2  OPENS EQUALS     188.5193 (S)
TIME LINK    3  OPENS EQUALS     268.0754 (S)
R (FT)=    0.00 TSL (F)=   256.3 QB (BTU/FT2 S)= 0.355E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=    5.64 TSL (F)=   219.0 QB (BTU/FT2 S)= 0.290E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   11.28 TSL (F)=   187.5 QB (BTU/FT2 S)= 0.231E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   16.92 TSL (F)=   159.5 QB (BTU/FT2 S)= 0.175E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   22.56 TSL (F)=   139.8 QB (BTU/FT2 S)= 0.134E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   28.20 TSL (F)=   126.1 QB (BTU/FT2 S)= 0.104E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   33.85 TSL (F)=   116.5 QB (BTU/FT2 S)= 0.831E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   39.49 TSL (F)=   109.6 QB (BTU/FT2 S)= 0.677E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   45.13 TSL (F)=   104.5 QB (BTU/FT2 S)= 0.563E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   50.77 TSL (F)=   100.7 QB (BTU/FT2 S)= 0.477E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   56.41 TSL (F)=    97.8 QB (BTU/FT2 S)= 0.411E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   62.05 TSL (F)=    95.5 QB (BTU/FT2 S)= 0.359E-01 QT (BTU/FT2 S)= 0.847E-18
TIME (S)=  300.000 LYR TEMP (F)=   252.0 LYR HT (FT)=   22.71 LYR MASS (LB)= 0.287E+04
FIRE OUTPUT (BTU/S)=  0.5918E+04 VENT AREA (FT2)=    192.00
LINK =  1 LINK TEMP (F)=  178.94 JET VELOCITY (FT/S)=     6.708 JET TEMP (F) =    307.8
LINK =  2 LINK TEMP (F)=  289.48 JET VELOCITY (FT/S)=     7.111 JET TEMP (F) =    311.4
LINK =  3 LINK TEMP (F)=  188.98 JET VELOCITY (FT/S)=     2.988 JET TEMP (F) =    210.8
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Figure 4. (Page 4 of 6 pages). Tabular format for the output - the default simulation.

```
TIME LINK    1  OPENS EQUALS      283.3156 (S)
TIME LINK    2  OPENS EQUALS      188.5193 (S)
TIME LINK    3  OPENS EQUALS      268.0754 (S)
R (FT)=    0.00 TSL (F)=   290.4 QB (BTU/FT2 S)= 0.361E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=    5.64 TSL (F)=   249.2 QB (BTU/FT2 S)= 0.305E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   11.28 TSL (F)=   213.3 QB (BTU/FT2 S)= 0.251E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   16.92 TSL (F)=   180.2 QB (BTU/FT2 S)= 0.196E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   22.56 TSL (F)=   156.1 QB (BTU/FT2 S)= 0.152E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   28.20 TSL (F)=   139.1 QB (BTU/FT2 S)= 0.120E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   33.85 TSL (F)=   126.9 QB (BTU/FT2 S)= 0.960E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   39.49 TSL (F)=   118.2 QB (BTU/FT2 S)= 0.785E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   45.13 TSL (F)=   111.7 QB (BTU/FT2 S)= 0.654E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   50.77 TSL (F)=   106.8 QB (BTU/FT2 S)= 0.555E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   56.41 TSL (F)=   103.1 QB (BTU/FT2 S)= 0.478E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   62.05 TSL (F)=   100.1 QB (BTU/FT2 S)= 0.418E-01 QT (BTU/FT2 S)= 0.847E-18
TIME (S)=  330.000 LYR TEMP (F)=   283.4 LYR HT (FT)=   24.18 LYR MASS (LB)= 0.219E+04
FIRE OUTPUT (BTU/S)=  0.6983E+04 VENT AREA (FT2)=    192.00
LINK =  1 LINK TEMP (F)=  204.76 JET VELOCITY (FT/S)=     6.730 JET TEMP (F) =    340.4
LINK =  2 LINK TEMP (F)=  322.67 JET VELOCITY (FT/S)=     7.112 JET TEMP (F) =    342.1
LINK =  3 LINK TEMP (F)=  211.02 JET VELOCITY (FT/S)=     2.988 JET TEMP (F) =    231.4
TIME LINK    1  OPENS EQUALS      283.3156 (S)
TIME LINK    2  OPENS EQUALS      188.5193 (S)
TIME LINK    3  OPENS EQUALS      268.0754 (S)
R (FT)=    0.00 TSL (F)=   320.3 QB (BTU/FT2 S)= 0.374E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=    5.64 TSL (F)=   276.8 QB (BTU/FT2 S)= 0.323E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   11.28 TSL (F)=   237.7 QB (BTU/FT2 S)= 0.270E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   16.92 TSL (F)=   200.5 QB (BTU/FT2 S)= 0.215E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   22.56 TSL (F)=   172.5 QB (BTU/FT2 S)= 0.169E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   28.20 TSL (F)=   152.2 QB (BTU/FT2 S)= 0.133E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   33.85 TSL (F)=   137.6 QB (BTU/FT2 S)= 0.107E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   39.49 TSL (F)=   126.9 QB (BTU/FT2 S)= 0.878E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   45.13 TSL (F)=   119.0 QB (BTU/FT2 S)= 0.733E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   50.77 TSL (F)=   113.0 QB (BTU/FT2 S)= 0.622E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   56.41 TSL (F)=   108.4 QB (BTU/FT2 S)= 0.536E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   62.05 TSL (F)=   104.8 QB (BTU/FT2 S)= 0.469E-01 QT (BTU/FT2 S)= 0.847E-18
TIME (S)=  360.000 LYR TEMP (F)=   306.7 LYR HT (FT)=   24.74 LYR MASS (LB)= 0.192E+04
FIRE OUTPUT (BTU/S)=  0.8048E+04 VENT AREA (FT2)=    192.00
LINK =  1 LINK TEMP (F)=  231.45 JET VELOCITY (FT/S)=     6.973 JET TEMP (F) =    367.7
LINK =  2 LINK TEMP (F)=  351.81 JET VELOCITY (FT/S)=     7.285 JET TEMP (F) =    368.8
LINK =  3 LINK TEMP (F)=  230.93 JET VELOCITY (FT/S)=     3.060 JET TEMP (F) =    248.8
TIME LINK    1  OPENS EQUALS      283.3156 (S)
TIME LINK    2  OPENS EQUALS      188.5193 (S)
TIME LINK    3  OPENS EQUALS      268.0754 (S)
R (FT)=    0.00 TSL (F)=   349.3 QB (BTU/FT2 S)= 0.393E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=    5.64 TSL (F)=   303.8 QB (BTU/FT2 S)= 0.342E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   11.28 TSL (F)=   261.9 QB (BTU/FT2 S)= 0.290E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   16.92 TSL (F)=   220.8 QB (BTU/FT2 S)= 0.232E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   22.56 TSL (F)=   188.9 QB (BTU/FT2 S)= 0.184E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   28.20 TSL (F)=   165.5 QB (BTU/FT2 S)= 0.146E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   33.85 TSL (F)=   148.4 QB (BTU/FT2 S)= 0.118E+00 QT (BTU/FT2 S)= 0.847E-18
```

Figure 4. (Page 5 of 6 pages). Tabular format for the output - the default simulation.

```
R (FT)=   39.49 TSL (F)=   135.8 QB (BTU/FT2 S)= 0.964E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   45.13 TSL (F)=   126.4 QB (BTU/FT2 S)= 0.805E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   50.77 TSL (F)=   119.3 QB (BTU/FT2 S)= 0.683E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   56.41 TSL (F)=   113.9 QB (BTU/FT2 S)= 0.589E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   62.05 TSL (F)=   109.6 QB (BTU/FT2 S)= 0.515E-01 QT (BTU/FT2 S)= 0.847E-18
TIME (S)=  390.000 LYR TEMP (F)=   326.6 LYR HT (FT)=   24.80 LYR MASS (LB)= 0.185E+04
FIRE OUTPUT (BTU/S)=  0.9113E+04 VENT AREA (FT2)=    192.00
LINK =  1 LINK TEMP (F)=  258.66 JET VELOCITY (FT/S)=     7.362 JET TEMP (F) =    393.5
LINK =  2 LINK TEMP (F)=  378.44 JET VELOCITY (FT/S)=     7.560 JET TEMP (F) =    394.3
LINK =  3 LINK TEMP (F)=  248.86 JET VELOCITY (FT/S)=     3.176 JET TEMP (F) =    265.0
TIME LINK    1  OPENS EQUALS     283.3156 (S)
TIME LINK    2  OPENS EQUALS     188.5193 (S)
TIME LINK    3  OPENS EQUALS     268.0754 (S)
R (FT)=    0.00 TSL (F)=   378.8 QB (BTU/FT2 S)= 0.413E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=    5.64 TSL (F)=   331.2 QB (BTU/FT2 S)= 0.363E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   11.28 TSL (F)=   286.3 QB (BTU/FT2 S)= 0.309E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   16.92 TSL (F)=   241.2 QB (BTU/FT2 S)= 0.249E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   22.56 TSL (F)=   205.5 QB (BTU/FT2 S)= 0.198E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   28.20 TSL (F)=   178.9 QB (BTU/FT2 S)= 0.158E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   33.85 TSL (F)=   159.3 QB (BTU/FT2 S)= 0.128E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   39.49 TSL (F)=   144.8 QB (BTU/FT2 S)= 0.105E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   45.13 TSL (F)=   134.0 QB (BTU/FT2 S)= 0.876E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   50.77 TSL (F)=   125.8 QB (BTU/FT2 S)= 0.744E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   56.41 TSL (F)=   119.4 QB (BTU/FT2 S)= 0.642E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   62.05 TSL (F)=   114.4 QB (BTU/FT2 S)= 0.561E-01 QT (BTU/FT2 S)= 0.847E-18
TIME (S)=  400.000 LYR TEMP (F)=   333.0 LYR HT (FT)=   24.76 LYR MASS (LB)= 0.185E+04
FIRE OUTPUT (BTU/S)=  0.9468E+04 VENT AREA (FT2)=    192.00
LINK =  1 LINK TEMP (F)=  267.83 JET VELOCITY (FT/S)=     7.499 JET TEMP (F) =    402.2
LINK =  2 LINK TEMP (F)=  387.14 JET VELOCITY (FT/S)=     7.658 JET TEMP (F) =    402.9
LINK =  3 LINK TEMP (F)=  254.59 JET VELOCITY (FT/S)=     3.217 JET TEMP (F) =    270.5
TIME LINK    1  OPENS EQUALS     283.3156 (S)
TIME LINK    2  OPENS EQUALS     188.5193 (S)
TIME LINK    3  OPENS EQUALS     268.0754 (S)
R (FT)=    0.00 TSL (F)=   388.7 QB (BTU/FT2 S)= 0.419E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=    5.64 TSL (F)=   340.3 QB (BTU/FT2 S)= 0.369E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   11.28 TSL (F)=   294.4 QB (BTU/FT2 S)= 0.315E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   16.92 TSL (F)=   248.1 QB (BTU/FT2 S)= 0.255E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   22.56 TSL (F)=   211.1 QB (BTU/FT2 S)= 0.203E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   28.20 TSL (F)=   183.5 QB (BTU/FT2 S)= 0.162E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   33.85 TSL (F)=   163.0 QB (BTU/FT2 S)= 0.131E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   39.49 TSL (F)=   147.9 QB (BTU/FT2 S)= 0.108E+00 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   45.13 TSL (F)=   136.5 QB (BTU/FT2 S)= 0.900E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   50.77 TSL (F)=   127.9 QB (BTU/FT2 S)= 0.764E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   56.41 TSL (F)=   121.3 QB (BTU/FT2 S)= 0.659E-01 QT (BTU/FT2 S)= 0.847E-18
R (FT)=   62.05 TSL (F)=   116.1 QB (BTU/FT2 S)= 0.576E-01 QT (BTU/FT2 S)= 0.847E-18
```

Figure 4. (Page 6 of 6 pages). Tabular format for the output - the default simulation.

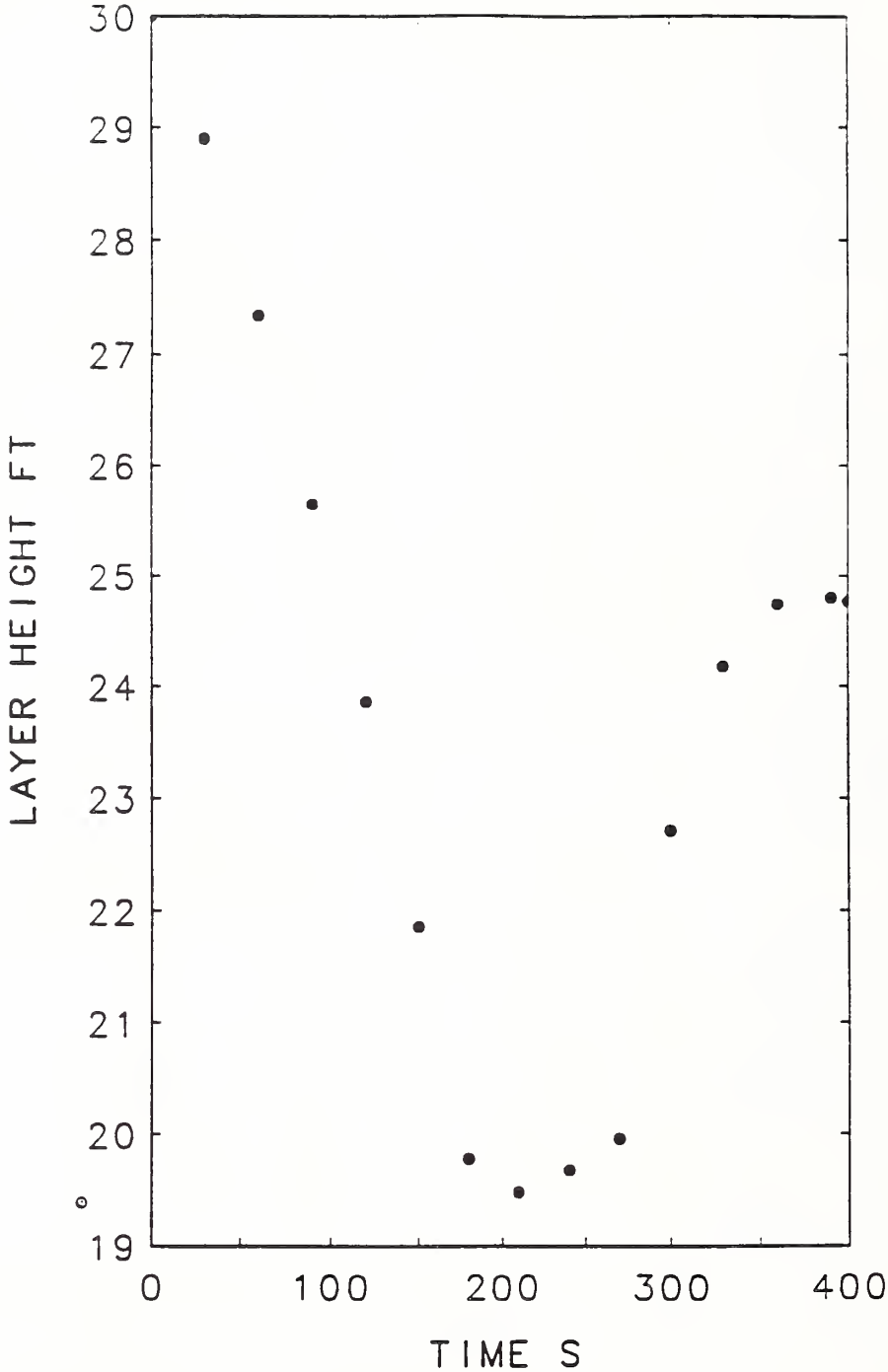

Figure 5. Plot of the height of the smoke layer interface vs time for the default simulation.

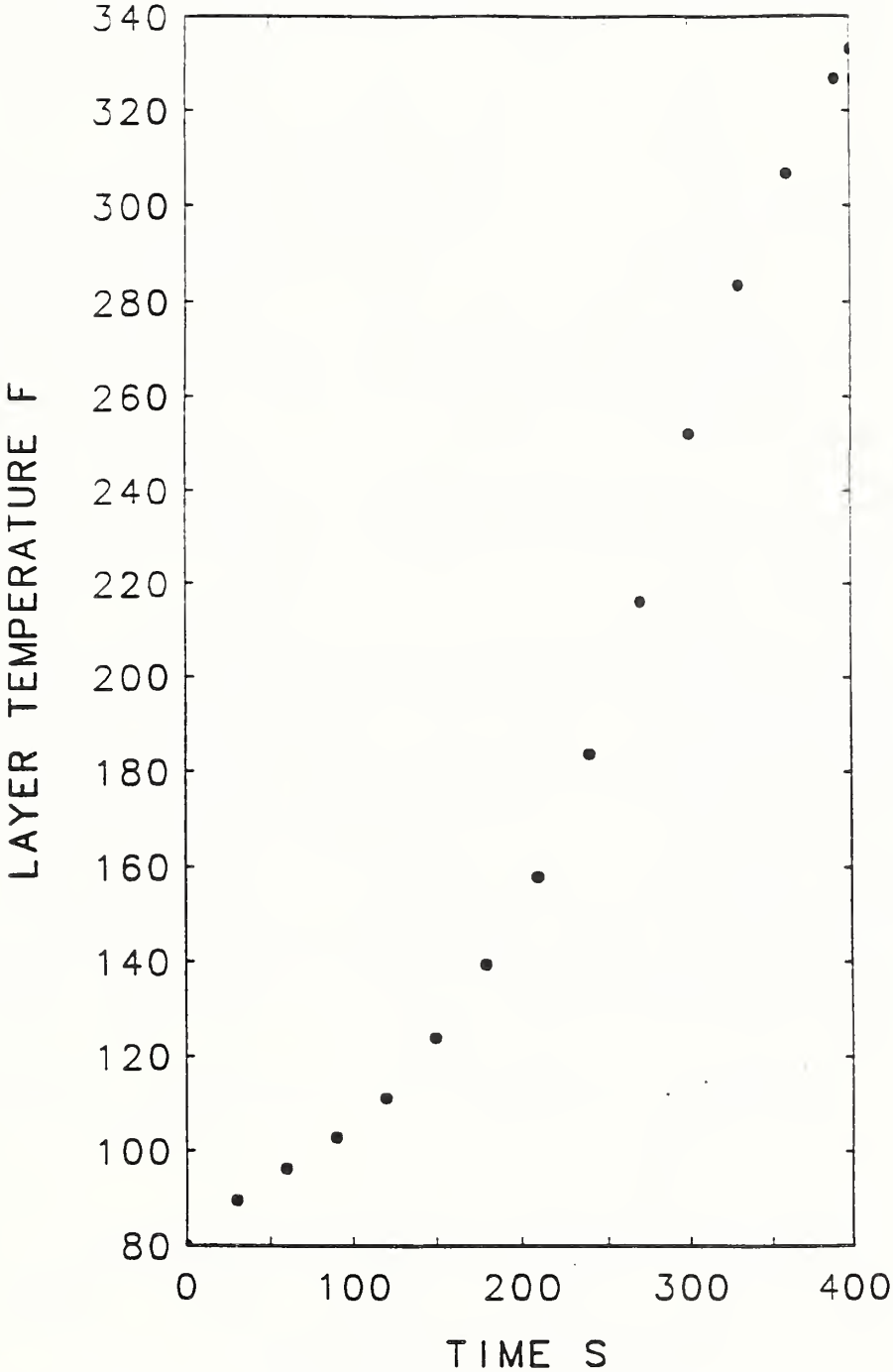

Figure 6. Plot of the temperature of the smoke layer vs time for the default simulation.

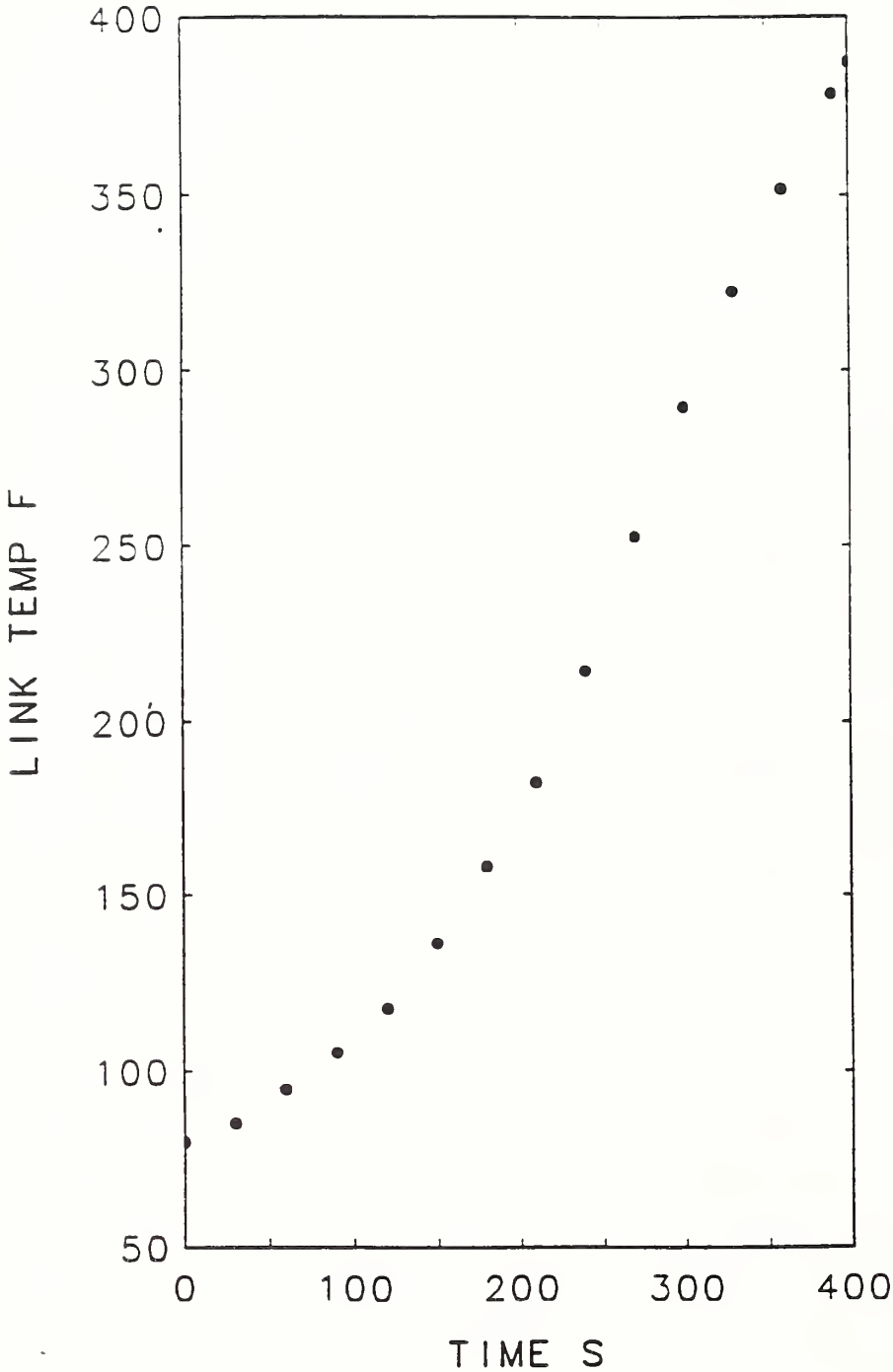

Figure 7. Plot of the closest (R = 21.2 ft) vent-link temperatures vs time for the default simulation.

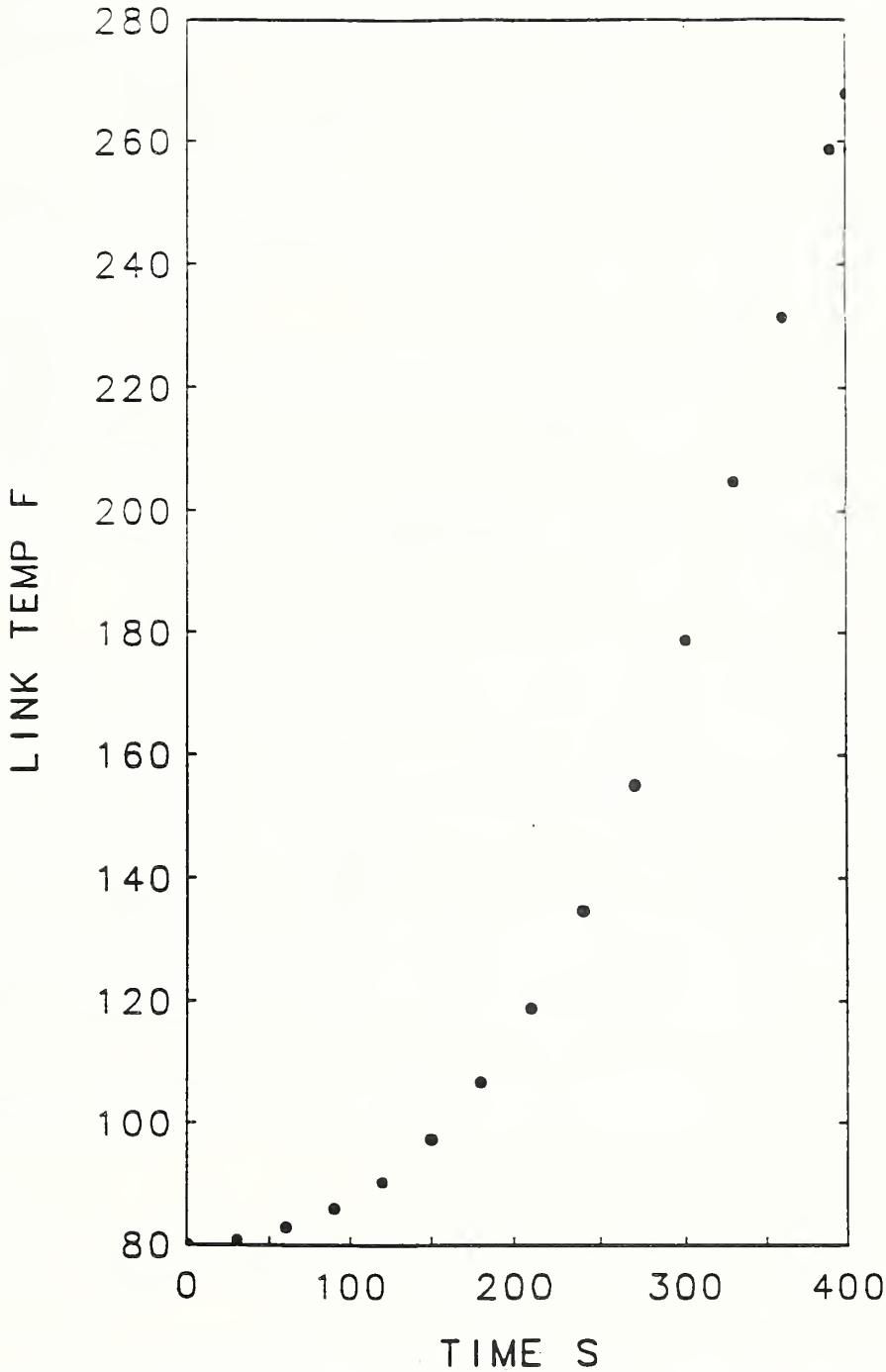

Figure 8. Plot of the far (R = 44.3 ft) pair of vent-link temperatures vs time for the default simulation.

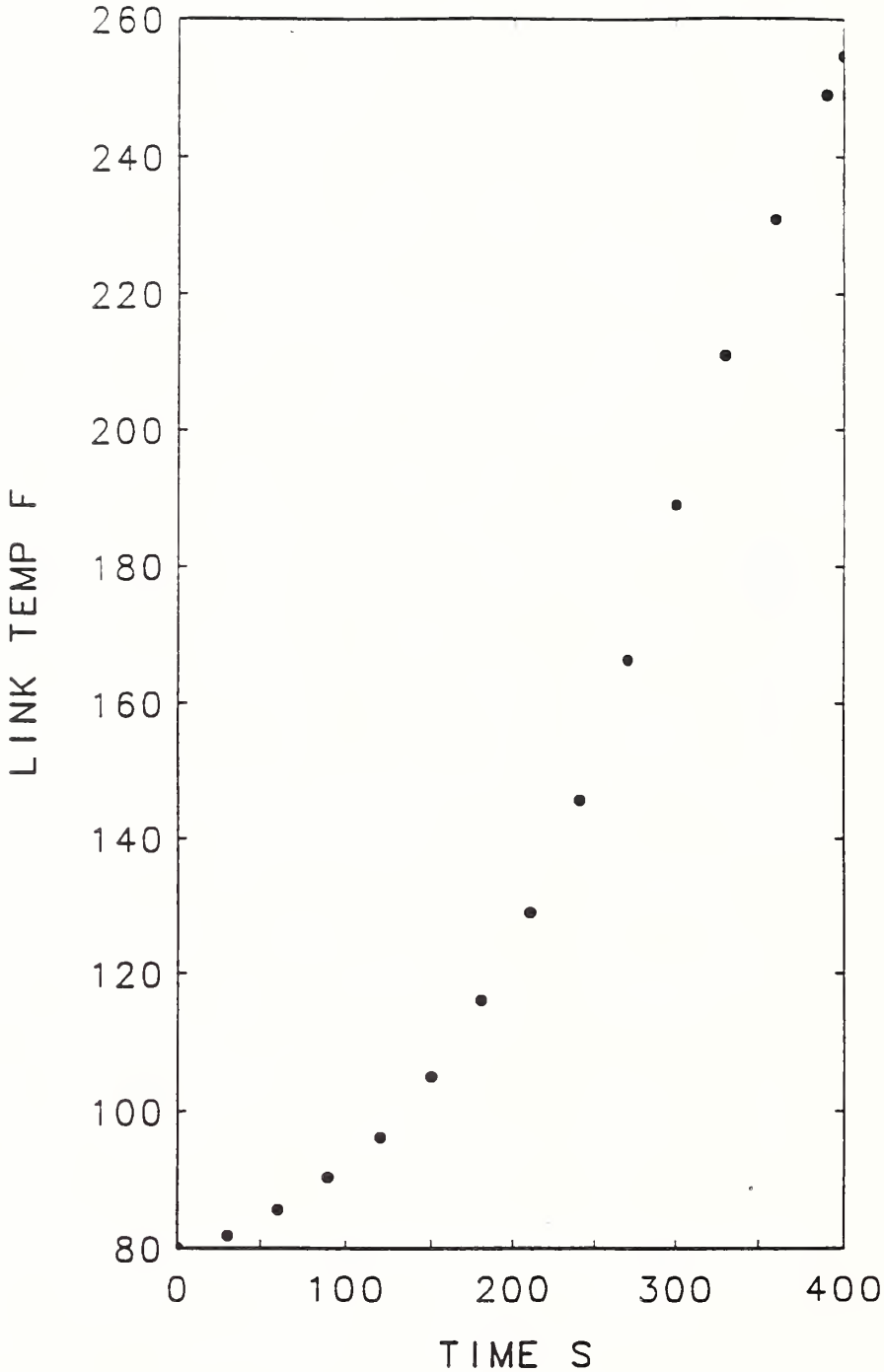

Figure 9. Plot of the closest (R = 6.0 ft) sprinkler-link temperatures vs time for the default simulation.

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5. AUTHOR(S)

William D. Davis and Leonard Y. Cooper

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This is a User Guide for the computer code LAVENT (Link-Actuated VENTs) and an associated graphics code GRAPH. LAVENT has been developed to simulate the environment and the response of sprinkler links in compartment fires with draft curtains and fusible-link-actuated ceiling vents.

The use of LAVENT is presented by a series of exercises in which the reader reviews and modifies a default input data file which describes vent and sprinkler actuation during fire growth in an array of wood pallets located in a curtained warehouse-type of configuration. Results of the default simulation are discussed.

LAVENT is written in FORTRAN 77. The executable code operates on PC-compatible computers and requires a minimum of 252 kilobytes of memory.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

building fires; compartment fires; computer models; fire models; mathematical models; vents; sprinkler response; zone models

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